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MOBILE FABRIC FILTER SYSTEM DESIGN AND FIELD TEST RESULTS

Robert R. Hall, et al

GCA Corporation

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16. ABSTRACT The report describes the design and operation of a mobile fabric filter system, and gives results of a laboratory fabric filter investigation. The mobile system, constructed to study the effects of fabric filtration parameters when filtering an actual industrial effluent stream, was designed for mechanical shake, pulse jet, or reverse flow cleaning. The mobile system was field-tested at a secondary brass foundry, a hot mix asphalt plant, and a coal-fired utility boiler. Woven and felted Nomex and woven glass fabrics were tested. The three cleaning methods were used with appropriate fabrics and emission sources. Pressure drop and efficiency (both mass and particle size) data were collected. Selected aspects of pulse jet and mechanical shake cleaned fabric filters were investigated in the laboratory. The effects of bag fit, pulse supply pressure, and pulse type on filter pressure drop and effluent were investigated. The mechanical shake cleaning tests determined the source of dust emissions for a specific aerosol/fabric combination. Dust emissions resulted from direct penetration, seepage, dust shaken through the filter during cleaning, and dust (loosened during cleaning) that penetrated when air flow resumed.

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July 1975

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CHAPTER I

INTRODUCTION

The high efficiency capabilities of fabric filters and the increasing need to control fine particulate emissions have resulted in an intensive effort to learn more about the parameters determining the performance of filter systems. Fabric filters are acknowledged to have a mass collection efficiency above 99 percent in most applications, but only limited data are available on their collection capabilities for fine particulates. Fabric filters are therefore the subject of many laboratory and field studies, some with special emphasis on fractional size efficiencies.

One advantage of laboratory experiments is that the experimenter can custom design the total system so that the parameters under study may be conveniently and systematically varied while those not being studied can be held constant. Draemel[1] was able to evaluate 123 fabrics with various dusts while studying the relationship between clean cloth fabric structural parameters, dust parameters, and filter performance. Such laboratory situations are well suited to wide ranging studies of the fundamental effects and interrelationships of fabric filter parameters. However, a major disadvantage of laboratory studies is that the test aerosol seldom, if ever, duplicates the real industrial aerosol.

The basic techniques for dust dispersion are compressed air dispersion and venturi mixing. These methods may fail to generate a fine particle distribution comparable to representative industrial sources because of incomplete dust redispersion. Many fine particulates encountered in the

field result from condensation processes, such as the zinc oxide fume from a secondary brass foundry. Although this operation could be simulated by boiling zinc in a chamber with sufficient oxygen to form zinc oxide, this technique would be difficult and not entirely satisfactory. In addition to duplicating the particle size and concentration properties of an actual field emission, one would also desire to duplicate the other aerosol properties such as chemical composition, density, shape and surface characteristics, and electric charge properties, as well as the temperature, humidity, and contaminants present in the gaseous stream. Problems in extrapolating laboratory performance to field performance are often encountered, since differences in aerosol properties such as those mentioned above are very common.

Field studies of operating industrial fabric filters do not, of course, present the problem of dust generation. The Environmental Protection Agency is sponsoring field tests that will provide important data on fabric filter performance during normal operations.[2,3] However, it is often not possible, or at least not practical, to vary the cleaning parameters, change the fabric, vary the filtration velocity, or make other changes in the operation of an industrial fabric filter. In order to study the effects of fabric filter parameters when filtering an actual industrial effluent stream, it is necessary to vary these parameters in the field. In addition, stack sampling on a full scale system is expensive and time consuming.

In an attempt to provide the experimental flexibility of a laboratory investigation and the real-world particulate effluent of an industrial source the Environmental Protection Agency contracted with the GCA/Technology Division to design, fabricate and operate a mobile fabric filter system. The system was designed so that the influence of the following parameters on fabric filter performance could be determined when filtering an actual industrial effluent:

Fabric type and properties
Particle size and other particulate characteristics
Filtration system configuration
Cleaning method.

The mobile fabric filter system was designed to be operated at temperatures up to 550°F and use up to seven filter bags. Automatic instruments for continuous unattended operation were provided. Mechanical shake, pulse jet or low pressure reverse flow cleaning may be used. The system design is summarized in Chapter II of this report and is described in detail in Reference 4.

Field tests were conducted in the following three sources in order to demonstrate the capabilities of the system and investigate, in a preliminary manner, the influence of the aforementioned aerosol and fabric filter parameters on fabric filter performance:

- secondary brass and bronze foundry
- hot mix asphalt plant
- coal-fired boiler.

At the conclusion of the field test program, the mobile system was delivered to the Environmental Protection Agency for use in a large scale field testing program involving other mobile particulate control devices including a mobile wet scrubber, and a mobile precipitator. The results of each field test are described in more detail in Chapter III of this report.

In addition to the design, fabrication and testing of the mobile filter system, laboratory filtration measurements were also performed during this program. The laboratory experiments were designed to amplify and/or clarify earlier results of our laboratory investigations[5] of cleaning by pulse jet and mechanical shaking. In the case of the pulse jet system, tests were conducted to determine the effects on system

efficiency and pressure drop of supply pressure, bag fit around the supporting cage and pulse type. With mechanically shaking systems several factors, suspected to contribute to total dust emissions, were investigated:

- Inlet dust passing directly through the filter
- Dust migrating through the filter by successive deposition and reentrainment due to aerodynamic and mechanical (vibrational) forces
- Dust dislodged from the shaken fabric during cleaning and penetrating to the clean air region
- Dust loosened during the cleaning process whose bonding forces are not strong enough to resist the dislodging forces when air flow is resumed.

The results of the laboratory program are described in Chapter IV of this report.

CHAPTER II

MOBILE FABRIC FILTER DESIGN

INTRODUCTION

The mobile fabric filter system is designed for the purpose of determining the effects of dust properties, fabric media, cleaning parameters, and other operating parameters on fabric filter performance. Specifically, the mobile fabric filter system has the following capabilities:

- Filtration can be conducted at cloth velocities as high as 20 ft/min* with a pressure differential up to 20 inches of water and at gas temperatures up to 550°F.
- The mobile system can be readily adapted to cleaning by mechanical shaking, pulse jet or low pressure reverse flow with the capacity to vary the cleaning parameters over broad ranges.
- The system can be operated in a series filtration mode.
- One to seven filter bags of any media, 4 to 10 feet long and up to 12 inches in diameter can be installed in the baghouse
- Automatic instruments and controls permit 24-hour operation of the system.

The system is transported to field sites on a 1-1/2 ton stake truck having a body platform 12 feet long and 7 feet wide. Although the equipment will be operated on the truck in most cases, it can be

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*Although it is EPA's policy to use the metric system for quantitative descriptions, the British system is used in this report. Readers who are more accustomed to metric units may use the table of conversions in the Appendix.

removed from the truck with a small truck-mounted crane and operated at locations not accessible to the truck. The heavier components of the system are the primary fan (about 400 pounds), the compressor (also about 400 pounds), the seven sections of the filter housing (total weight about 800 pounds), and the control console that weighs approximately 200 pounds. Figure 1 provides a schematic diagram of the mobile fabric filter system as set up for mechanical shake cleaning.

SPECIFIC DESIGN FEATURES

In order to minimize any possible corrosion problems caused by test aerosols or climatic factors, the seven-section filter housing was constructed of stainless steel (type 304). The 13- by 24-inch cross section of the filter housing was dictated by the number and sizes of the bags to be used and the typical upward gas velocities found in industrial fabric filters. The first filter housing section consists of a single compartment hopper with a rotary dust discharge valve, designed to operate at 550°F. Section two is a single compartment 4-foot section that is used primarily for pulse jet cleaning tests. The third section is a 6-foot single compartment that is used mainly for mechanical shake cleaning. Both the 6- and 4-foot sections can be assembled in series so that bags up to 10 feet long may be used. A three-compartment filter housing and hopper were also constructed so that the mobile system could be operated as a three-compartment mechanical shake cleaned system. In addition, the three-compartment system was designed so that the series filtration concept could be evaluated with mechanical shaking. In the series filtration mode, the effluent from a just-cleaned bag would be recycled to the system inlet. Separate top sections have been built for shake cleaning and pulse jet cleaning. Reverse flow cleaning can be employed with either of the two top sections cited above.

In the mechanical shake or reverse flow cleaning mode, up to three filter bags can be used, while in the pulse jet cleaning mode up to seven bags

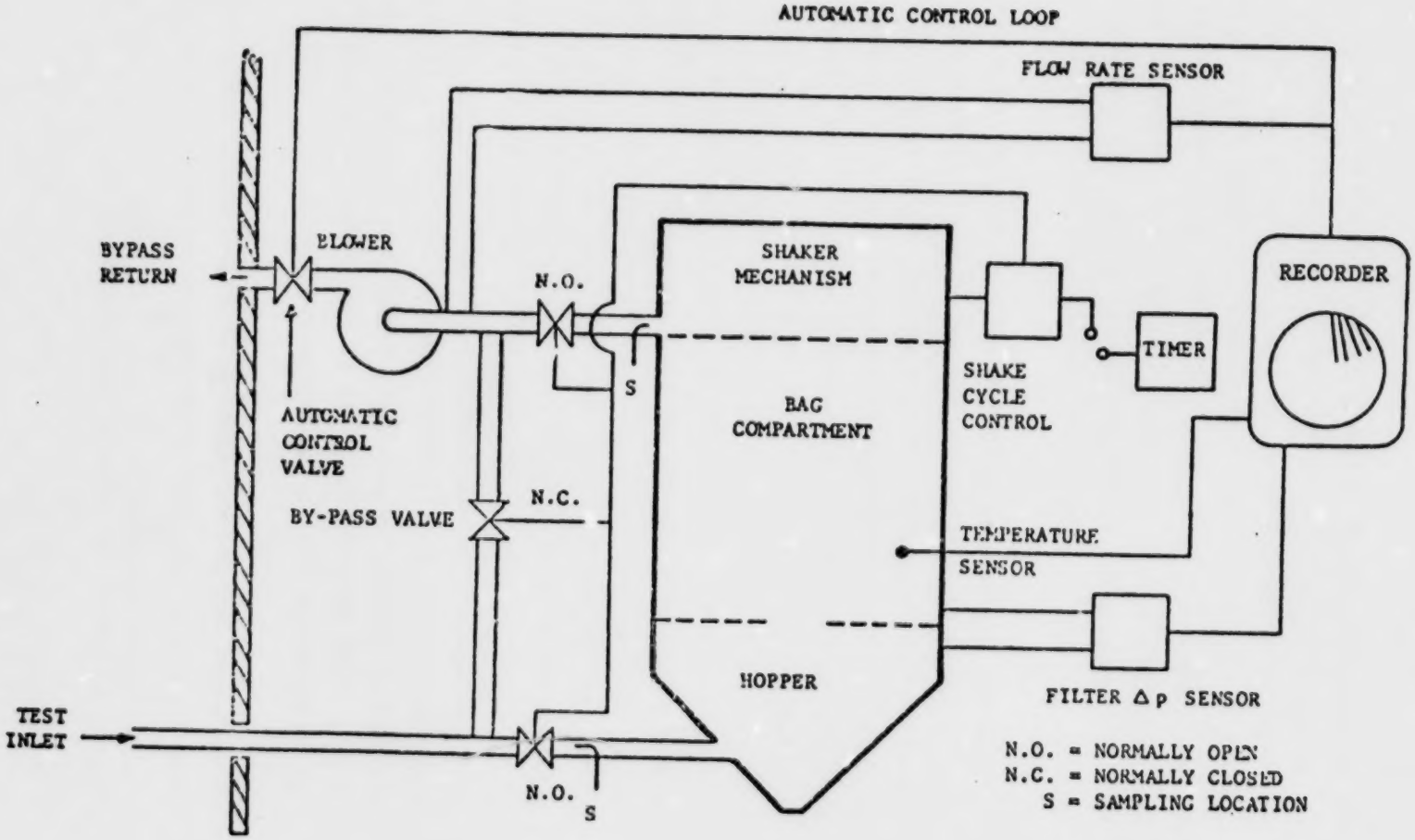

Figure 1. Mechanical shaking system control arrangement

can be installed. Reverse flow and pulse jet cleaning are conducted in the single compartment filter housings. Mechanical shaking tests can be conducted in the single or the three-compartment filter housing. Several of the possible bag arrangements are shown in Figure 2. Bags 4 feet, 6 feet, and 10 feet long can be evaluated with mechanical shaking or reverse flow cleaning. Any bag length up to 10 feet can be used in the pulse jet cleaning mode. To accommodate the required lengths, housing sections may be stacked as shown in Figure 3.

An apparatus designed to shake one to three bags was constructed. The shaking motion, applied to the top end of each bag, is adjustable with regard to amplitude* from 3/8 to 3 inches. A 1/2 hp permanent magnet DC motor and a solid state speed controller is used to select and regulate shaking frequency over a working range of 2 to 15 cps. Frequency is measured through a microswitch on the motor which drives a counter mounted on the control console. Pneumatic clutches permit shaking of one bag at a time. This option was included to simulate operation of a three-compartment system, and to allow special series filtration tests. The bag suspension points can be adjusted vertically in order to regulate the bag tension. Bags may be attached at the top either by a loop or by a cap arrangement. Removable windows at the top and bottom of the filter housing permit easy access to the bags and quick changing of filter media. The amplitude and frequency range for the shaking apparatus was chosen to encompass that usually encountered in the field and also to provide the necessary energy transmission to clean the fabric. With minor changes, the present frequency and amplitude range can be increased if test conditions require it.

An apparatus designed to clean up to seven bags by high pressure reverse pulse jet was constructed using standard commercial valves, venturis,

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*Amplitude is 1/2 the peak-to-peak displacement.

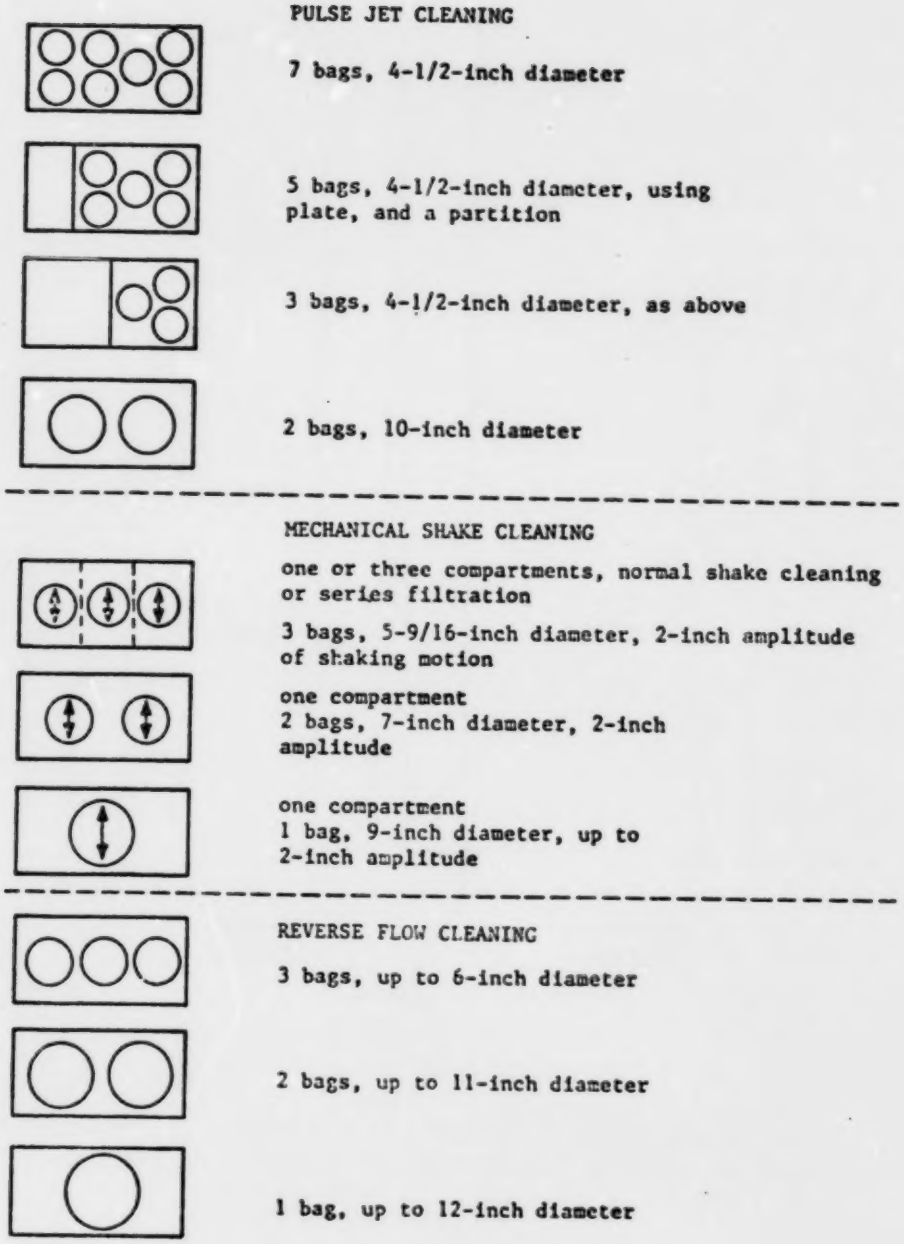
PULSE JET CLEANING
7 bags, 4-1/2-inch diameter
5 bags, 4-1/2-inch diameter, using plate, and a partition
3 bags, 4-1/2-inch diameter, as above
2 bags, 10-inch diameter
MECHANICAL SHAKE CLEANING
one or three compartments, normal shake cleaning or series filtration
3 bags, 5-9/16-inch diameter, 2-inch amplitude of shaking motion
one compartment
2 bags, 7-inch diameter, 2-inch amplitude
one compartment
1 bag, 9-inch diameter, up to 2-inch amplitude
REVERSE FLOW CLEANING
3 bags, up to 6-inch diameter
2 bags, up to 11-inch diameter
1 bag, up to 12-inch diameter

Figure 2. Some bag arrangements possible in a 13- by 24-inch housing (top view)

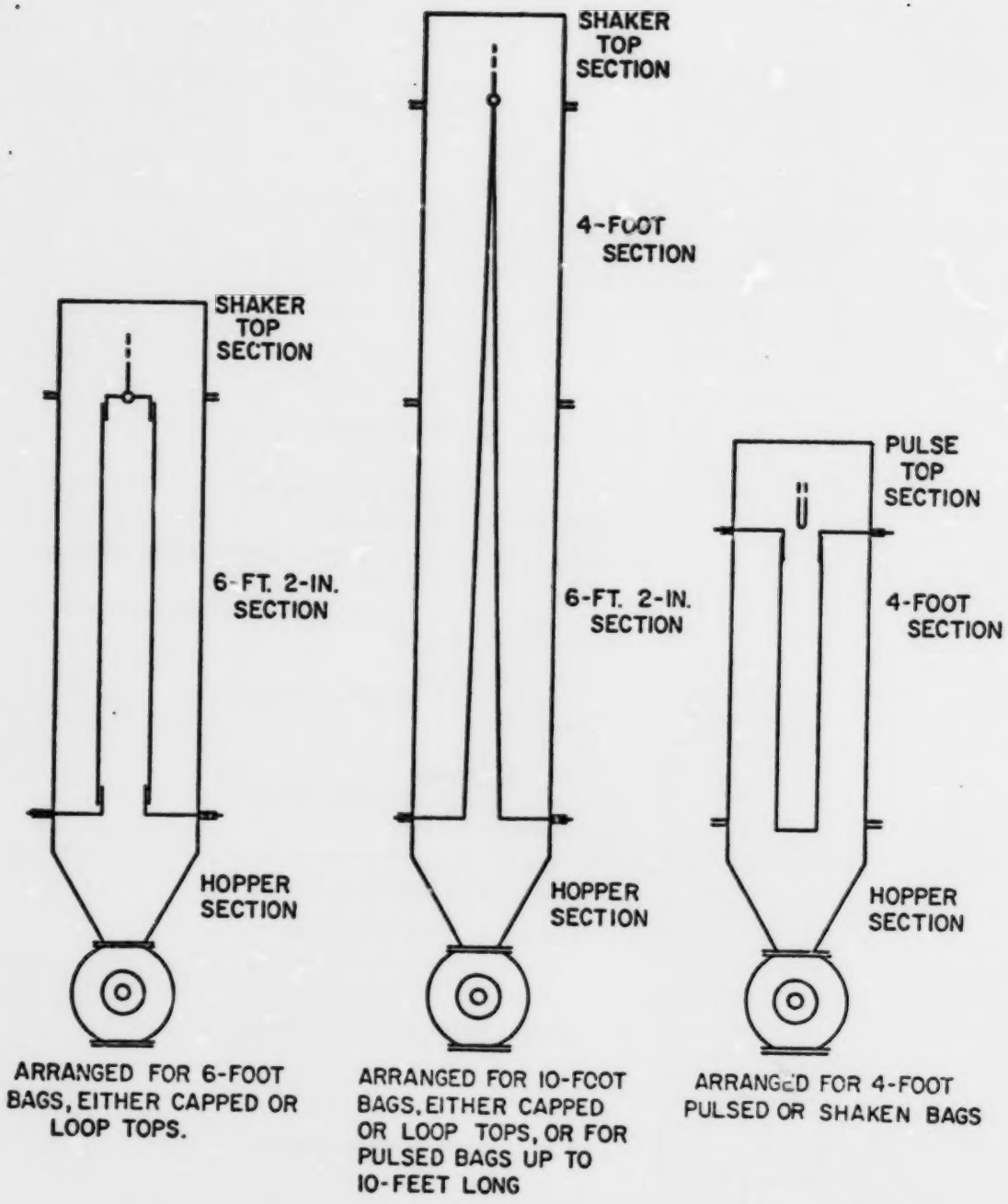
SHAKER TOP SECTION
6-FT. 2-IN. SECTION
HOPPER SECTION
ARRANGED FOR 6-FOOT BAGS, EITHER CAPPED OR LOOP TOPS.
SHAKER TOP SECTION
4-FOOT SECTION
6-FT. 2-IN. SECTION
HOPPER SECTION
ARRANGED FOR 10-FOOT BAGS, EITHER CAPPED OR LOOP TOPS, OR FOR PULSED BAGS UP TO 10-FEET LONG
PULSE TOP SECTION
4-FOOT SECTION
HOPPER SECTION
ARRANGED FOR 4-FOOT PULSED OR SHAKEN BAGS

Figure 3. Several possible housing section arrangements

bag cages, and bags purchased from Mikropul.* A 5-gallon pressure tank is mounted immediately on top of the pulse jet unit in order to maintain supply air pressure during pulsing. Compressed air is provided by a compressor with a delivery of 8.3 ft^3/min (STP)+ at 90 to 125 psig. A digital solid state timer is used to set the exact length of the signal that activates the solenoid valve that controls the pulse. The amount of air that is delivered per pulse for various pulse durations and reservoir pressure was measured so that the economics of a particular cleaning method could be evaluated.

The low pressure reverse flow cleaning fan is designed to supply air at a minimum back pressure of at least 2 inches of water to a filter system having a cloth area of about 30 ft^2. Based on an estimated minimum residual drag of 0.5 inches water/ft/min, this pressure capability will require flows up to 120 ft^3/min. For high temperature operation, especially when the aerosol contains appreciable amounts of water vapor, the filter bags must not be cooled during the reverse flow phase. Therefore, a heat exchanger or direct flame heater will be used to heat the reverse flow air when necessary. An orifice meter, a damper valve, and the previously mentioned automatic valves are the other components used during reverse flow operation.

Gas flows ranging from 26 to 280 ft^3/min, as determined by cloth velocity, bag size, and bag number, must be carried by the mobile system ducting. In order to minimize dust settlement and prevent excessive pressure drop, dust velocities should be maintained between 2000 and 4000 feet per minute. Thin walled, 1-1/2- to 3-inch stainless steel pipe connected by reusable Morris couplings‡ was selected for the mobile system ducting.

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*Mikropul Division, U.S. Filter Company, Chatham Road, Summit, N.J. 07901.

+All volumes and flows are at actual conditions unless otherwise designated.

‡Morris Coupling and Clamp Company, 2240 West 15th Street, Erie, Pa. 16512.

The primary fan for the mobile fabric filter is a Chicago Turbo-Pressure Blower* capable of supplying 21 inches of water suction at 550°F. At ambient conditions with a 5 hp motor it delivers 420 ft^3/min against 42 inches of water resistance. Although the fan is designed primarily for relatively clean air at the fabric filter outlet, it can be and has been used briefly on dusty air.

Automatic valves for diverting the gas flow when cleaning by shaking or reverse flow were fabricated by GCA. These modified gate valves, which provide tight sealing during shutoff and also relatively fast response, are able to operate at high and varying temperatures. These valves have a tested leak rate of less than 0.01 ft^3/min at 20 inches of water pressure differential. It is essential that flow through the filter be shut off during mechanical shake cleaning.

The system pressure, flow, temperature, time controlling, and recording instruments are located in a single control console. Flow through the fabric filter is indicated by the differential pressure across a Stairmand type disk. The latter device is ideally a symmetrically located disk with a diameter equal to one half that of the duct. Flow through the outer annular region provides good dust mixing under turbulent flow conditions. The above pressure differential and that across the fabric filter are displayed and recorded on a dual channel recorder. A penumatic controller permits automatic operation at either constant flow or constant filter pressure drop. Constant flow through a single bag or compartment is often used in laboratory experiments to simplify data reduction, and the same operating mode can be used with the mobile system when filtering a real aerosol. On the other hand, a baghouse with 14 compartments applied to a coal-fired power plant, such as the Pennsylvania Power and Light Company's Sunbury plant, would operate at

---

*Chicago Blower Corporation, 1675 Gley Ellyn Road, Glendale Heights, Ill. 60137.

a constant pressure drop with the velocity varying from compartment to compartment. One compartment of such a system can be simulated by the mobile system in the constant filter pressure drop mode.

Gas temperature through the mobile system must be maintained above the dew point and below the temperature limit of the particular fabric. The ducting, filter housing, and fan are heated with high temperature heating tapes and insulated with fiberglass. A thermocouple recorder with an on - off controller and adjustable high and low set points is used to control the gas temperature. The controller can be used to activate a portion of the heating tape capacity at the low set point and, if necessary, to open one of the previously mentioned automatic valves for dilution cooling at the high set point.

Automatic timing of the system operating and cleaning cycles is provided. Five timers and two stepping switches control the system when using the single compartment mechanical shake cleaning, as previously depicted in Figure 1. The first timer (T_1), with a range of 3 to 60 minutes, controls the filtration time. At the end of the filtering interval, timer T_1 causes the bypass valve to open, the valves isolating the filter housing to close, and timer T_2 to start. The second timer (T_2) provides a delay time for the isolation valves to close, engages through a stepping switch the bag or bags to be shaken and initiates the shaking. Timer T_3 or T_4 then controls the length of the shaking cycle. T_3 has a range of 1 to 10 seconds for short shaking cycles, and T_4 has a range of 11 to 150 seconds for longer cycles. After the shaking has ceased, timer T_5 allows a delay of 0.25 to 5 minutes for the dust to settle and then restarts the filtering cycle as controlled by timer T_1. The same timers are used for the three compartment mechanical shake cleaning system except that an additional stepping switch closes additional valves as needed to isolate a single compartment while the other compartments remain on line. Reverse flow cleaning uses the same timers as the mechanical shaking system but timers T_3 and T_4 operate the reverse flow fan in lieu of the shaker

motor. A different control system consisting of two timers and a stepping switch is used to operate the pulse jet cleaning system. The first of these timers sets the interval between pulses, 0.25 to 5 minutes, while the second timer sets the length of the pulse, 0.01 to 99 seconds. The stepping swith selects the bag to be cleaned.

Electric power is distributed to all components of the mobile fabric filter system through circuit breakers and receptacles located at the rear of the control console.

A variety of sampling and measurement techniques are needed to evaluate filter efficiency on a mass and/or number basis. Inlet mass concentration can be determined by conventional sampling with glass fiber papers or by weighing the dust collected in the hopper over some selected averaging period. Downstream mass concentrations can usually be determined over longer averaging periods with glass fiber filter papers provided that the concentration is not too low. A condensation nuclei counter and diffuser-denuder can be used to determine number concentrations for fine particles in the range of 0.01 to 0.1 microns. Particle size concentrations before and after the fabric filter can be determined by impactor measurements. A Brink impactor* operated at 0.03 to 0.1 ft^3/min is generally used before the fabric filter while the higher flow rate, 0.5 to 0.8 ft^3/min, Andersen impactor+ is used on the downstream side. Mass sampling and impactor measurements on the downstream side of the fabric filter are usually conducted over periods of at least 2 hours, in order to collect a reasonable mass.

Additional design details are presented within later sections of this report in conjunction with the discussion of specific field tests.

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*Monsanto Enviro-Chem Systems, Inc., 800 North Lindbergh Blvd., St. Louis, Mo. 63166.

+Andersen 2000 Inc., P. O. Box 20769, Atlanta, Ga. 30320

CHAPTER III

MOBILE FABRIC FILTER SYSTEM FIELD TESTS

INTRODUCTION

The mobile fabric filter system was designed to investigate the effects of fabric type, particulate characteristics, cleaning method and cleaning parameters on actual industrial emissions. One purpose of the field tests conducted during this program was to investigate, in a preliminary manner, the above fabric filtration parameters. An additional objective was to detect and eliminate any mobile system operating problems before delivery to EPA. The field test program demonstrated the versatility of the mobile fabric filter system and the wide variety of fabric filter parameters that can be investigated with the mobile system.

In line with the above objectives, field tests of relatively short duration were conducted at three different industrial emission sources. During the first field test at a secondary brass and bronze foundry, the mobile system was operated in the pulse jet, mechanical shake, and reverse flow cleaning modes. The first three brass foundry tests (each 7 hours long) were conducted in the pulse jet cleaning mode using Nomex felt bags. The system was then rearranged, and four tests were conducted in the mechanical shake cleaning mode with woven Nomex bags. Reverse flow cleaning was used in the last brass foundry test. For the next series of tests the system was transported to a hot mix asphalt plant. A total of five 8-hour tests using pulse jet cleaning were conducted at

this facility. The final field tests were at a coal-fired electric power plant where the system was operated in the mechanical shake cleaning mode with woven glass bags for three 8-hour tests.

The field test program demonstrated the capabilities and utility of the mobile fabric filter system. However, the data collected are subject to some limitations. The available time for testing precluded extensive replicate mass and particle size sampling. This problem was compounded by process variations during the brass foundry and hot mix asphalt plant operations. Fabric filter equilibration time for the field operations was usually less than 8 hours before collection of performance data began. Although some variations in cleaning parameters were investigated briefly, optimum performance of the mobile fabric filter could not be established in the time available. Many of the results presented should be treated semiquantitatively due to the aforementioned time limitations. Although the data have limitations due to the nature of the particular field tests and the usual field testing problems, they do represent a significant advance from laboratory testing in that real industrial aerosols were filtered.

FIELD TESTS AT A SECONDARY BRASS AND BRONZE FOUNDRY

Background

Secondary brass and bronze foundries or refineries remelt copper base scrap metal containing significant amounts of tin, lead, and zinc. Brass and bronze are copper-based alloys with zinc or tin, respectively, as the second largest component. The scrap is usually melted in a gas- or oil-fired reverberatory furnace. During the melting process, scrap metal of varying but controlled composition, and various fluxes are charged to the furnace. Mass emissions vary widely depending upon the zinc and lead content of the melt. The emissions from brass refining are composed mainly of zinc oxide and lead oxide formed by evaporation, condensation,

and oxidation processes. Particle size is reported to be between 0.03 and 0.3 microns[6] with the range of size attributable to the agglomeration of the small particles in transit between the furnace and emission control device.

Fabric filters are the most frequently employed collectors for fumes from secondary brass processes. Many fabrics have been used, the choice depending mainly on the gas temperature. The most common practice is to operate at elevated temperatures using either woven glass or Nomex bags and mechanical shake cleaning. Based upon a typical brass foundry melting capacity of 50 tons/day[7] and an emission factor for an uncontrolled reverberatory furnace of 70 lb/ton,[8] such an operation could emit 1.8 tons/day. Regulations for new secondary brass refineries limit emissions to 0.022 grain/dscf,[9] necessitating a collection efficiency of about 99 percent. Therefore, it is important that the capabilities for controlling fine particulates by fabric filtration be investigated at these installations.

Mobile Fabric Filter Installation

During foundry field tests, the mobile fabric filter system was operated in the pulse jet, mechanical shake, and reverse flow cleaning modes. The literature indicates that the vast majority of industrial fabric filters installed on sources of metallic fume use either mechanical shake or reverse flow cleaning. However, because pulse jet cleaning has come into wide use for many sources, an investigation of its applicability to a metallic fume appeared to be appropriate.

The mobile fabric filter system was operated on the truck. The plant effluent was extracted approximately isokinetically at 70 to 100 ft^3/min through a 3.3-inch nozzle from the main duct about 45 feet upstream of the plant fabric filter. Lightweight 2.5-inch OD stainless steel tubing was used for the remainder of the necessary piping leading to the mobile

unit. Fiberglass insulation and heating tape were used to maintain inlet gas temperature to the mobile fabric filter in the 250 to 350°F range.

Process Description

The brass refining is performed in an oil-fired, cylindrical reverberatory furnace in which 45,000 pounds of scrap metal is melted per 7-hour melting cycle. Three basic steps constitute the melting cycle:

Step 1. About 30 percent of the total scrap metal is charged to the furnace and heated for 140 minutes.

Step 2. The oil burner is shut down and 23 percent of the total scrap metal is charged over a 15- to 20-minute period.

Step 3. After charging, oil firing is resumed, and the furnace is heated for 70 to 85 minutes.

Steps 2 and 3 are repeated three times before the melting process is terminated.

Because emissions are negligible during the step 2 shutdown, the mobile fabric filter system operation was modified to avoid overcleaning. In the case of pulse jet cleaning this involved a manual shutdown of the automatic timing system so that pulsing was interrupted during the oil burner shutdown. Since most of the emissions occured during the 7-hour melting cycle, the mobile system was operated only during the melting cycle. Emissions are negligible during the ingot pouring process which was begun at the conclusion of the melting process.

The furnace charge composition during the pulse jet tests is indicated below:

Material	Weight %
Copper	77 - 79
Tin	2 - 3.3
Lead	6 - 8
Zinc	9.8 - 14.5
Nickel	0 - 1.0
Iron	0 - 0.4

Aerosol Properties and Particulate Sampling Procedures

Particulate concentrations entering the mobile fabric filter were determined by isokinetic sampling, with collection on glass fiber filters, and by the weight of dust collected in the filter hopper. During charging, the inlet mass concentration was less than 0.05 grain/ft^3(STP), while during each heating cycle the concentration varied between 1 grain/ft^3(STP) at the start and 2 to 2.5 grains/ft^3(STP) at the end of the cycle. Average inlet dust concentration, exclusive of the charging period, was 1.7 grain/ft^3(STP). Three Brink impactor measurements were made, each on a different day, to determine the inlet particle size distribution. The results, assuming spherical particles and a density of 1 gm/cm^3, show a mass median diameter of 0.5 μm. Results of the Brink impactor measurements were in good agreement. Figure 4 shows the inlet particle size distribution.

Pulse Jet Cleaning

Operating and Cleaning Parameters - Nomex felt bags, 16 oz. per square yard, were used for the pulse jet cleaning tests. Principal filtration parameters for the three bag system (4-1/2 in. diameter and 4 ft long) are shown in Table 1. The gas flow followed the conventional "outside to inside" direction used commercially with wire-cage-supported felt tubes. The filter velocity was maintained at an average of 8 ft/min so that the total flow was 110 ft^3/min with a cloth area of 13.9 ft^2.

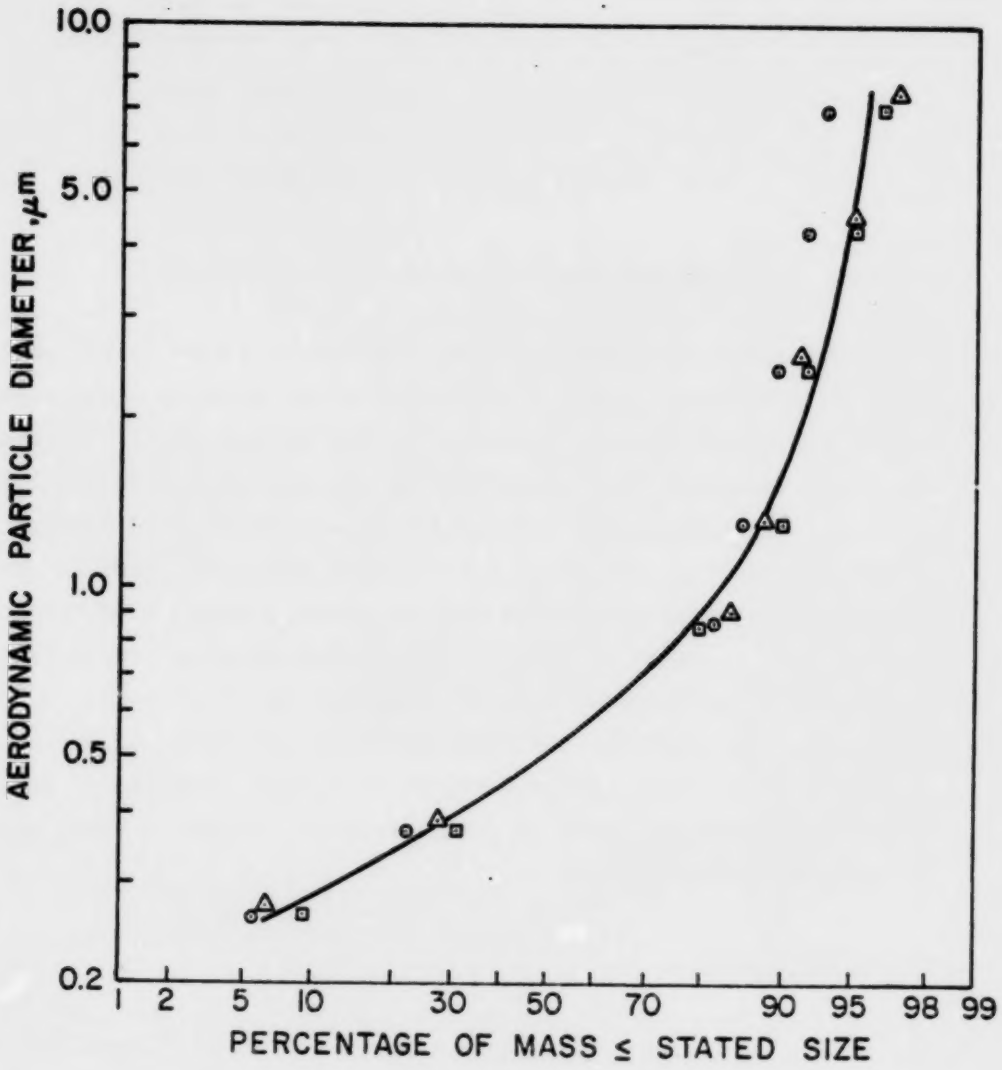

Figure 4. Inlet particle size distribution for zinc oxide fumes, from brass refining furnace by Brink cascade impactor

Table 1. PRINCIPAL FILTRATION PARAMETERS FOR BRASS FUME FILTRATION BY MOBILE PULSE JET FILTER SYSTEM

	Test 1	Test 2	Test 3
Bag characteristics			
Material	Nomex felt	[a]	[a]
Weight, oz/yd^2	16	[a]	[a]
Length, ft	4	[a]	[a]
Diameter, in	4.5	[a]	[a]
Filter area (effective) ft^2	13.9	[a]	[a]
Manufacturer	Menardi Southern Augusta, Georgia	[a]	[a]
Part No.	17563	[a]	[a]
Cleaning Parameters			
Number of bags	3	[a]	[a]
Pulse frequency, min^{-1}	1.5	1.5	3
Cycle time, min	2	2	1
Pulse duration, sec[b]	0.1	[a]	[a]
Pulse supply pressure, psig	60-80	80	80
Compressed air requirement, ft^3/min/1000 ft^2[c]	40[d]	40[d]	80[d]
Average filtration conditions			
Air to cloth ratio, ft/min	8	[a]	[a]
Gas flow, ft^3/min	110	[a]	[a]
Temperature, ^{o}F	320	[a]	[a]
Inlet dust concentration, grains/ft^3(STP)	1.7	1.7	1.6
Inlet dust size,[e] microns	0.5	[a]	[a]

[a] Values were the same as Test 1.

[b] Electrical signal to valve. True valve open time was 0.15 sec.

[c] Standard cubic feet per minute of compressed air per 1000 square feet of filter area.

[d] About 0.37 ft^3(STP) pulse.

[e] Aerodynamic mass median diameter.

Average filtration temperature was 320°F. The fabric filter was run for a complete 7-hour cycle before the collection of performance data was undertaken. Although longer equilibration time would have been preferred, the above period was considered sufficient for preliminary assessment of pulse jet cleaning process feasibility.

The pulse jet cleaning parameters were included in Table 1. The interval between pulses was 40 seconds for the first two tests and 20 seconds for the third test. Since the cleaning was continuous and three bags were operated, the total time to cycle through all the bags was 120 seconds for the first two tests and 60 seconds for the last test. Pulse duration was a nominal 0.1 second, as set on an electronic timer for all tests. The above time duration actually designates the electrical "open time" and not the effective open time of the valve (about 0.15 sec) whose motion lags significantly electrical start-stop signals. Pulse supply pressure was 80 psig except for the first half ot Test No. 1 when the pressure was 60 psig. The volume of compressed air used by the pulse jet cleaning system, a very important economic consideration, was estimated to be 40 ft^3/min per 1000 ft^2 of filtration area for the first two tests and 80ft^3/min per 1000 ft^2 during the last test. (Equivalent to 7.3 and 14.6 ft^3 per 1000 ft^3 of gas filtered at standard conditions).

Results of Field Measurements - Fabric filter performance for each of the three pulse cleaning tests is summarized in Table 2. The filter pressure drop shown in Table 2 is the average for each test with the peak pressure drop given in parentheses. During test 3, in which the filter bags were cleaned twice as much, the average pressure drop across the filter was only 5 inches of water as compared to 10 and 9 inches of water respectively for the first two tests. On the negative side, the increased cleaning frequency also doubled the percent penetration. Percent penetration was 0.081 and 0.078 percent for the first two tests, but increased to 0.17 percent during the last test. Corresponding efficiencies for the first and second tests were 99.919 and 99.926 percent, and for the third test 99.83 percent. Tests 1 and 2 are

Table 2. PULSE JET CLEANING PERFORMANCE SUMMARY, BRASS FUME FILTRATION

	Test 1	Test 2	Test 3
Test duration, hr	7	7	7
Filtration velocity, ft/min	8	8	8
Average filter pressure drop, in water	10(14)[a]	9(13)[a]	5(6)[a]
Inlet particle size,[b] microns	0.5	0.5	0.5
Average inlet concentration, grains/ft^3(STP)	1.7	1.7	1.6
Average outlet concentration, grains/ft^3(STP)	0.0014	0.0013	0.0028
Number of outlet samples	3	2	3
Outlet sampling times, hr	1,0.7,1	2,1	1.5,1.5,1
Average penetration, percent	0.081	0.078	0.17
Average efficiency, percent	99.919	99.922	99.83

[a]Filter pressure drop varied widely. Values in parentheses indicate the highest pressure drop for each test.

[b]Mass median aerodynamic diameter.

approximate replicates despite the lower pulse supply pressure at the start of test 1. Effluent concentration (and source strength) were approximately doubled as a result of the increased cleaning frequency.

Two Andersen impactor samples (in stack design with glass fiber substrates but used out of stack because of the small duct dimensions) were taken at the fabric filter outlet in an effort to determine effluent size properties. Insufficient material was collected on any of the impactor states, however, to determine accurately the effluent characteristics despite sampling times of 1 to 2 hours. Most of the exiting fume was collected on the Andersen back-up filter ($\leq$ 0.5 microns) indicating that the outlet aerosol was slightly smaller than the inlet aerosol. The failure to collect a significant amount of material on the Anderson impactor was the result of the high filter efficiency and the small inlet particle size (mass median diameter 0.5 μm and 85 percent by weight less than 1 μm, see Figure 4).

Because fabric filter pressure drop is a very important design consideration, graphs of filter pressure drop versus time are presented in Figures 5 through 7 for Tests 1 through 3. Figure 5 shows the instantaneous pressure drop across the filter versus time during Test 1. After 2-1/2 hours, the furnace oil burner was shut down for charging during which interval the fume loading to the fabric filter was very low. A few pulses lowered the pressure drop to about 4 inches of water. At this time, the pulse cleaning unit was shut off until the furnace was re-ignited as evidenced by a rapid rise in the filter pressure drop. The pulse cleaning system was shut down during charging operations so that the bags would not be excessively overcleaned. The perturbations in pressure drop are assumed to reflect variations in the inlet dust concentration.

Figure 6 compares the pressure drop versus time relationships for Test 1 (solid line) and Test 2 (dotted line). The filter pressure drop was

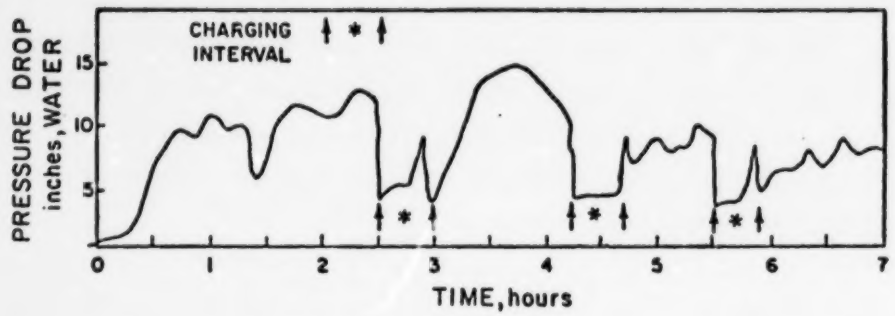

Figure 5. Filter pressure-drop time relationship for brass fume filtration with pulse jet cleaning, Test 1

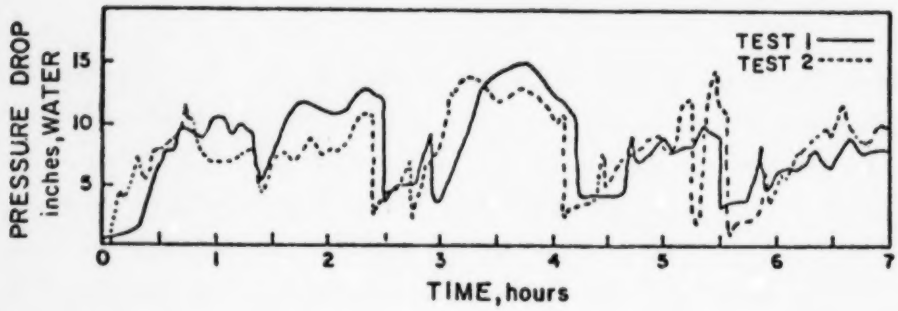

Figure 6. Filter pressure-drop time relationship for brass fume filtration with pulse jet cleaning, comparison of Tests 1 and 2

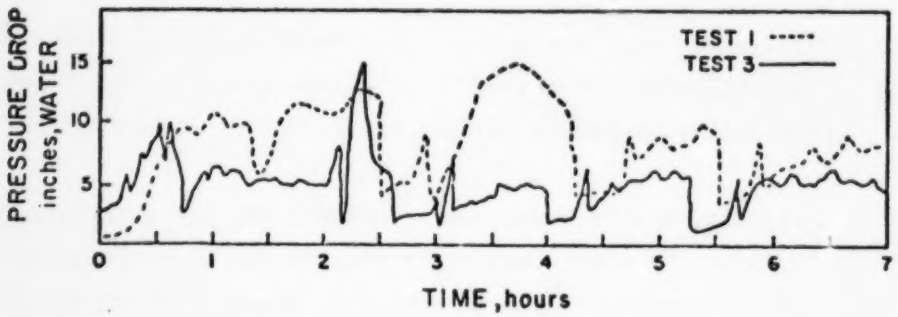

Figure 7. Filter pressure-drop time relationship for brass fume filtration with pulse jet cleaning, comparison of Tests 1 and 3

lower during the first half of Test 2 because the pulse supply pressure was 80 psig, compared to 60 psig during the first half of Test 1. After 5-1/2 hours of Test 2 there was a sudden rise in the pressure drop because the pulse jet cleaning system had been prematurely shut down. Generally, the variations in filter pressure drop throughout Tests 1 and 2 are similar.

In Figure 7 the pressure drop versus time results for Test 1 (dotted line) and Test 3 (solid line) are compared. The lower pressure drop during Test 3 reflects the doubled pulse rate. The transient high pressure drop at the start of Test 3 was caused by a stepping switch malfunction that reduced the pulse frequency.

The pulse jet cleaning tests suggest that the fine metal oxide fume from a secondary brass smelter can be filtered efficiently (~99.8 percent) with Nomex felt bags at a cloth velocity of 8 ft/min. By using 80 ft^3/min (STP) of compressed air per 1000 ft^2 of filter area, the average filter pressure drop was maintained near 5 inches of water. It should be noted that the reported compressed air consumption (manufacturer data) for many industrial processes is often lower, ranging from 5 to 30 ft^3/min (STP).[10,11,12] In the present situation, however, time did not allow investigation of the feasibility of changing pulse jet parameters or filtration velocity so as to reduce compressed air volumes (or delivery costs). The filter bags showed no signs of plugging or blinding after 28 hours in use. The life span of Nomex bags in this type of operation, of course, cannot be determined from short period tests.

Manufacturers of Nomex media (DuPont) and bag manufacturers (Globe Albany) indicate, however, that Nomex fabrics should perform well at temperature and in atmospheres characterized by brass smelting operations. It is expected that in the long-term average filter resistance would gradually increase due to normal plugging such that pressure loss might rise by an inch or 2 of water over a 2-year period.

Mechanical Shake Cleaning

Background - Several field measurements were also performed using a conventional mechanical shaking system with woven Nomex bags, the latter conforming in fabric properties to those used in the main foundry fume control system from which the test stream was extracted. The objective of these tests was to simulate the operation of the plant fabric filter system so that by varying cleaning parameters on the mobile system the performance of the plant system might be improved or better understood. Foundry personnel have had problems with excessive pressure drops across the plant fabric filter with the result that the system ventilation capability has been significantly reduced. Shake cleaning parameters cannot be varied conveniently on the plant fabric filter without major mechanical modifications.

Nomex filament fabric was used in the four-compartment plant system with a design filtration velocity of 3 ft/min. A nearly horizontal shaking motion with an amplitude of 1/4 to 1/2 inch and a frequency of 3 cps was used to clean the bags. The bags were spring-tensioned at approximately 10 pounds. Filter chambers were cleaned sequentially after 20 minutes of filtration with 1 minute allowed for shaking and 1 minute allowed for dust settlement prior to returning to line. Rough Pitotstatic tube measurements indicated that the actual filtration velocity, at 10 inches of water pressure drop across the filter, was only 1.5 to 2 ft/min.

System Operating and Cleaning Parameters - The Nomex fabric used in the mobile system was approximately the same as the plant gas cleaning equipment. The mobile system bags were 6 feet long and 5-9/16 inches in diameter while the plant system used bags 8-1/2 feet long and 5-1/2 inches in diameter.

In the field gas cleaning system each row of bags was hung from a frame which in turn was suspended from 6-inch arms at each end. The frame oscillated at a frequency of about 3 cps with a slight arc imparted by

the 6-inch arms. If the bags had been securely fastened to the frame the bag motion would have been identical to that of the mobile unit (i.e., a radial length of 6 inches for the shaker arm). However, the bags were actually secured to the frame through spring loaded hooks such that the lateral displacement was diminished. Because the bag motion in the mobile system follows a slightly arcing path not modified by a spring in contrast to the plant system, the bag tension on the mobile system was set lower than the plant filter. For the initial simulation of the plant system the amplitude was 3/8 inch, the shaking frequency was 3 cps, and the filtration velocity was 3 ft/min. The mobile system was operated as a single compartment as a simulation of one compartment of the plant system. At an amplitude of 3/8 inch and a frequency of 3 cps, the maximum acceleration of the shaker arm was estimated to be 0.34 g.* Based upon prior GCA tests,[5] which indicated poor cleaning for g levels below 4 to 5, effective cleaning was not expected for either the plant or mobile filter system.

Particulate properties and, therefore, conditions for Tests 4 and 6 differed from those of the pulse jet cleaning tests because the brass melts contained less zinc, 4.5 to 6.0 percent versus 9.75 to 14.5 percent for the earlier pulse cleaning studies. Detailed data on brass compositions are presented in Table 3.

Table 3. BRASS COMPOSITIONS DURING MECHANICAL SHAKING TESTS

Composition	Weight percent	
	Brass type 1 Tests 4 and 6	Brass type 2 Tests 5 and 7
Copper	84.0 - 86.0	77.0 - 79.0
Tin	4.4 - 6.0	2.0 - 3.25
Lead	4.0 - 5.7	6.0 - 8.0
Zinc	4.5 - 6.0	9.75 - 14.5
Nickel	0.5 - 1.0	0.0 - 1.0
Iron	0.0 - 0.25	0.0 - 0.4

*1 g = 32.2 ft/sec.^{2}

A summary of the principal filtration parameters for the mechanical shaking tests is presented in Table 4.

RESULTS OF FIELD MEASUREMENTS

The average inlet fume concentrations during Tests 4 and 6 were 0.65 and 0.54 grains/ft^3(STP), respectively, compared to 1.7 grains/ft^3(STP) during the pulse jet cleaning tests. The lowered concentration can be attributed to the reduced zinc content. During mechanical shake cleaning Tests 5 and 7, the same type of brass was produced as that during the pulse jet cleaning tests. However, the average inlet dust concentration was only 0.90 to 0.92 grains/ft^3(STP) as compared to 1.6 grains/ft^3(STP) for the pulse jet cleaning tests.

Test 4 was designed to simulate the operation of the plant fabric filter. As expected, based upon plant experience, very little cleaning was evidenced during the first 2 hours of this test. According to the pressure drop-time curve of Figure 8, the resistance rose to 14 inches water, and even after shaking was only slightly reduced to 13 inches water.

After 3 hours, the shaking frequency was increased to 5 cps which increased the shaker arm acceleration to 0.96 g. However, cleaning was still not significantly improved. After 4 hours, the shaking frequency was increased to 6 cps (a shaker arm acceleration of 1.4 g) but the cleaning remained unsatisfactory. At the end of the test, the filtration velocity had fallen to 2.3 ft/min but the pressure drop was near 16 inches of water. It is emphasized here that the mobile system flow would probably have decreased to much lower levels than the 2.3 ft/min cited above, had a conventional exhauster been used ($\sim$10 inches water static pressure limit). Because of the need for flexibility in the mobile system, a special high static, thin scroll centrifugal fan was selected that minimized flow variations. Further evidence of poor cleaning was the small amount of dust, 50 to 100 grams, collected in the hopper during

Table 4. PRINCIPAL FILTRATION PARAMETERS FOR BRASS FUME FILTRATION BY MOBILE MECHANICAL SHAKING FILTER SYSTEM

	Test 4	Test 5	Test 6	Test 7
Bag characteristics				
Material	Nomex woven filament	[a]	[a]	[a]
Weight, oz/yd^2	4.5	[a]	[a]	[a]
Weave	3 x 1 twill	[a]	[a]	[a]
Thread count	98 x 79	[a]	[a]	[a]
Clean cloth permeability[b]	18	[a]	[a]	[a]
Length, ft	6	[a]	[a]	[a]
Diameter, in	5-9/16	[a]	[a]	[a]
Number of bags	3	[a]	[a]	[a]
Manufacturer	Globe Albany, Buffalo, N.Y.	[a]	[a]	[a]
Part No.	850	[a]	[a]	[a]
Cleaning parameters				
Number of compartments	1	[a]	[a]	[a]
Filtration cycle				
Filtering, min.	20	[a]	[a]	[a]
Pause, min	0.25	[a]	[a]	[a]
Shaking, min	1	[a]	[a]	[a]
Dust settling, min.	1	[a]	[a]	[a]
Shaker arm amplitude, in	3/8	7/8	7/8	7/8
Shaker arm frequency, cps	3-6	6	6-8	6
Shaker arm acceleration,[c] g's	0.34-1.4	3.2	3.2-5.7	3.2
Static tension, lb	5	2	1	1
Average filtration conditions				
Air to cloth ratio, ft/min	3-2.3	3	3	2.5,2.0
Gas flow, ft^3/min	73-56	73	73	61-49
Temperature, ^{o}F	240	270	270	270
Inlet dust concentration grains/ft^3(STP)	0.65	0.92	0.54	0.90
Inlet particle size,[c] μm	0.5	[a]	[a]	[a]

[a] Values were the same as Test 1.

[b] Gas flow in ft^3/min per ft^2 of cloth area at a pressure drop of 1/2 inch water.

[c] Acceleration = $4\pi^2$ (frequency)^2 (amplitude).

[d] Aerodynamic mass median diameter, composite of all impactor samples.

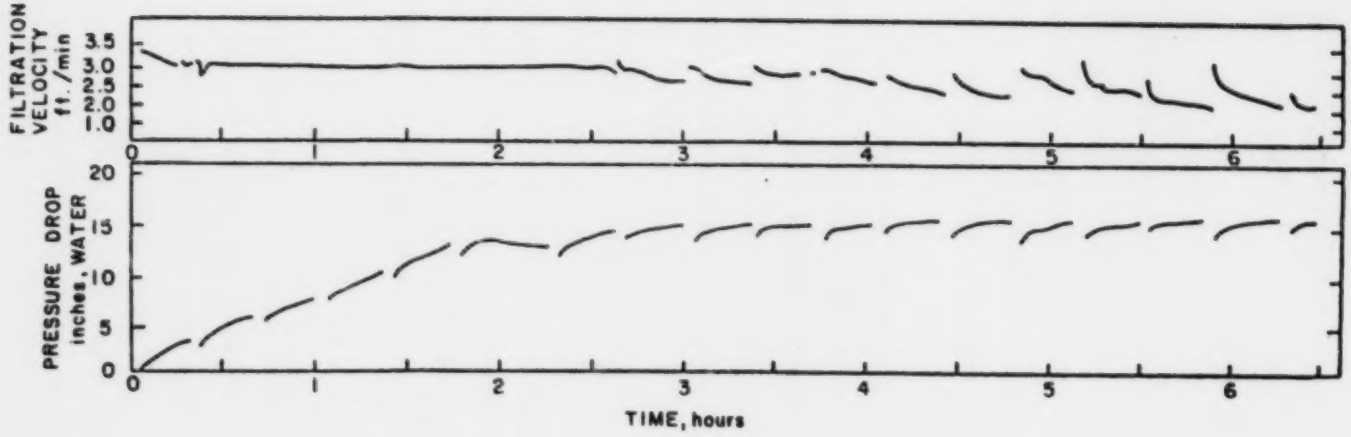

Figure 8. Filter pressure drop-time relationship for brass fume filtration with mechanical shaking, Test 4

the entire 7-hour test. At the end of the test the bags were shaken by hand and about 640 grams of dust were collected. After being shaken by hand, the pressure drop across the bags was reduced to only 1 inch of water at 3 ft/min velocity.

In an attempt to improve collector performance, shaking amplitude was increased to 7/8 inch during Test 6 and the bag tension adjusted to about 1 pound. The shaking frequency was maintained at 6 cps for the first hour of filtration followed by an increase to 8 cps for the remainder of the test. The alloy composition and fume inlet concentration were approximately the same as those noted for Test 4. The energy imparted to the shaking bags, as defined by shaker arm acceleration, was 3.2 and 5.7 g's, respectively, for the two frequency levels. In Figure 9 the graphs of filter resistance and filtration velocity versus time show a marked improvement for the higher shaking amplitude (dashed line) relative to the system performance obtained under Test 4 conditions (solid line). After 2 hours of filtration, the pressure drop across the bags was 9 inches of water instead of 14 inches as in the previous test. Filter pressure drop after cleaning was reduced by 3 inches of water compared to less than 1 inch for Test 4. Through most of Test 6, filter pressure drop was maintained between 8.6 and 10.6 inches of water while, at its termination, the pressure drop was 11 inches of water at a velocity of 3 ft/min compared to 16 inches of water at 2.3 ft/min in the previous test.

A net 20 to 50 grams of dust were dislodged after each cleaning cycle instead of a total of 50 to 100 grams for the entire test. Additionally, only 100 grams of dust were collected by hand shaking at the end of Test 6 compared to 640 grams in Test 4. It was concluded that increasing the shaking frequency and amplitude (both contributing to higher bag acceleration) reduced the filter pressure drop and increased the filtration capacity.

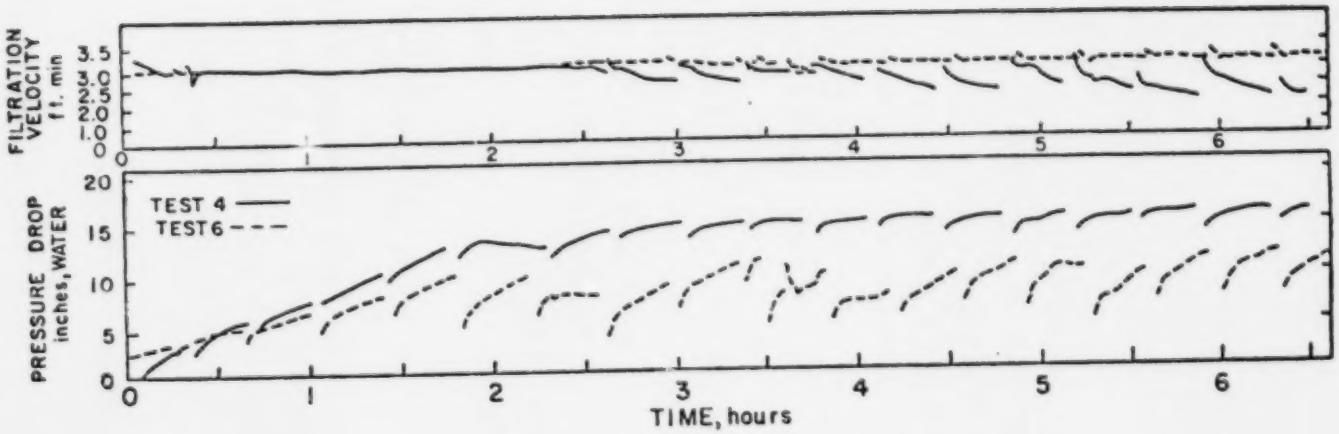

Figure 9. Filter pressure-drop relationship for brass fume filtration with mechanical shaking, comparison of Tests 4 and 6

Average fume penetration was 0.08 percent during Test 4 and 0.16 percent during Test 6. The results are consistent with theory which indicates an inverse relation between dust penetration and filter dust holding.[5] One can also infer that the more intense acceleration, and particularly the increase in shaking amplitude, would enlarge the filter pores, thus allowing more dust to penetrate the fabric structure.

Tests 5 and 7, Figure 10, reflect mobile filter system operation at the higher fume loadings (see Table 4) obtained with the high zinc alloys. Test 5 was run at a filtration velocity of 3 ft/min, a shaking amplitude of 7/8 inch, and a shaking frequency of 6 cps. The pressure drop characteristics were only slightly higher than those for test 6 despite the lower shaker arm acceleration of 3.2 g's and the higher inlet dust concentration of 0.9 grains/ft^3(STP). Tests 5 and 7 were the same except for the lower filtration velocity during test 7. During test 7 the filtration velocity was 2.5 ft/min for the first half and 2.0 ft/min for the remaining time. The resultant lower pressure drop is clearly shown in Figure 10. The lower penetration measured during test 7 is attributed to the fact that residual dust holding should be greater with less vigorous shaking, 3.2 versus 5.7 g's, and the lower filtration velocity should permit enhanced diffusional capture of fine particles. The specific dust fabric resistance coefficient $K_2 \left(\frac{\text{in. } H_2O/\text{ft/min}}{\text{lb/ft}^2}\right)$, as calculated for various periods throughout the mechanical shake cleaning tests, ranged from 150 to 300. Only very limited K_2 values (ranging from 40 to 180)[13] for zinc oxide filtration are reported in the literature. Results of mechanical shake cleaning tests are summarized in Table 5.

Low Pressure Reverse Flow Cleaning

A single 7-hour test using low pressure reverse flow cleaning was conducted. The primary objective of this test was to shake down the mobile

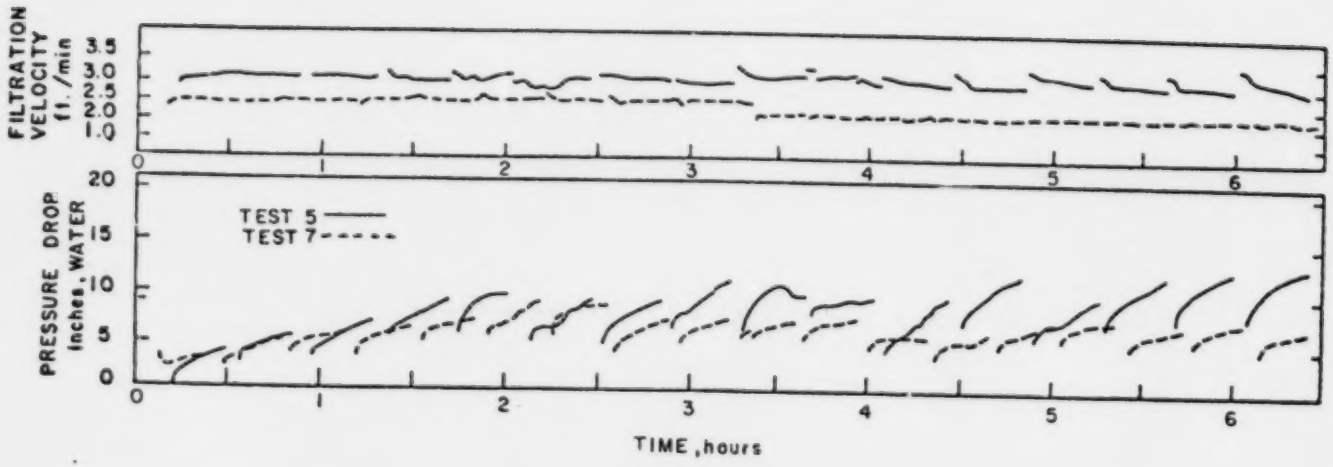

Figure 10. Filter pressure-drop time relationship for brass fume filtration with mechanical shaking, comparison of Tests 5 and 7

Table 5. MECHANICAL SHAKE CLEANING PERFORMANCE SUMMARY, BRASS FUME FILTRATION

	Test 4	Test 5	Test 6	Test 7
Test duration	7	7	7	7
Filtration velocity, ft/min	3-2.3	3	3	2.5,2.0
Average filter pressure drop,[a] in. water	16	9	9	7.5,6
Inlet particle size,[b] microns	0.5	0.5	0.5	0.5
Average inlet concentration, grains/ft^3(STP)	0.65	0.92	0.54	0.90
Average outlet concentration, grains ft^3(STP)	0.0005	0.0012	0.00087	0.0003
Number of outlet samples	1	3	4	4
Outlet sampling times, hr	0.8	1,1,1	1,1,1.1,1	1,1,1,1
Average penetration, percent	0.08	0.14	0.16	0.05
Average efficiency, percent	99.92	99.86	99.84	99.95

[a]The first 2 hours of each test was not included in the determination of average filter pressure drop.

[a]Mass median aerodynamic diameter.

fabric filter system in the reverse flow cleaning mode. A secondary objective was to collect performance data on the filtration of a metallic fume by a reverse flow cleaned fabric filter.

System Operating and Cleaning Parameters - The woven Nomex bags used for the reverse flow cleaning tests were the same bags that had been used for mechanical shake cleaning (see Table 4). Bag tension was increased to 20 pounds for the reverse flow test. The operating cycle consisted of 20 minutes filtration , a 15-second pause, 50 seconds of reverse flow, and a 1-minute pause for dust settlement. About 25 seconds were required for the reverse flow fan to reach full speed, giving a 25-second cleaning time at full flow. Ambient air at about 40°F was used for reverse flow. Filtration velocity was 3 ft/min at the start of the test and was reduced to 2.5 ft/min after 2 hours.

Reverse flow air was estimated on the basis the reverse flow pressure drop and the terminal filter pressure drop. Since the flow is laminar, flow is directly proportional to pressure drop. The reverse flow can be estimated from the normal flow, the terminal filter pressure drop and the initial reverse flow pressure drop. Reverse flow rate was 0.9 ft/min during the first 2 hours and the 0.4 ft/min during the remainder of the test.

During the reverse flow test, an alloy having the following composition was manufactured:

Material	Weight %
Copper	86.75 - 88.75
Tin	5.75 - 6.5
Lead	1.0 - 1.5
Zinc	3.0 - 5.0
Nickel	0.7 - 1.0
Iron	Less than 0.15

This alloy is classified as a leaded tin bronze. The lead and zinc content is lower than the previous alloys and the copper content is higher. Average inlet concentration to the mobile filter system was 0.75 grain/ft^3(STP). The particle size should have been similar to the previous tests, approximately 0.5 microns mass median diameter.

Results - The average outlet concentration during the reverse flow cleaning test was determined from four 1-hour samples. The average outlet concentration was 0.00025 grain/ft^3(STP) with a range from 0.0002 to 0.001 grain/ft^3(STP). Since the inlet concentration averaged 0.75 grain/ft^3(STP), the percent penetration was 0.033 percent, and the collection efficiency was 99.967 percent.

Figure 11 presents the filter pressure drop during the reverse flow cleaning test. After 2-1/2 hours of testing, the filter pressure drop was 13 inches of water and the filtration velocity was falling below 3 ft/min. Reverse flow during this period was 0.9 ft/min, and the back pressure generated was 4 inches of water. Clearly this combination of filtration velocity and cleaning parameters was not successful.

After 2-1/2 hours, the filtration velocity was lowered to 2.5 ft/min and the reverse flow air was lowered to 0.4 ft/min, about 2 inches of water back pressure. This procedure appeared to give slightly better results. Pressure drop was maintained below 12 inches of water and the filtration velocity was maintained at 2.5 ft/min. Large decreases in filter pressure drop during charging periods and the short duration of the test period make it difficult to judge the effectiveness of reverse flow cleaning in this application. In addition, investigation of other changes in cleaning parameters such as instituting a more sudden start to the reverse flow might have yielded better results.[5]

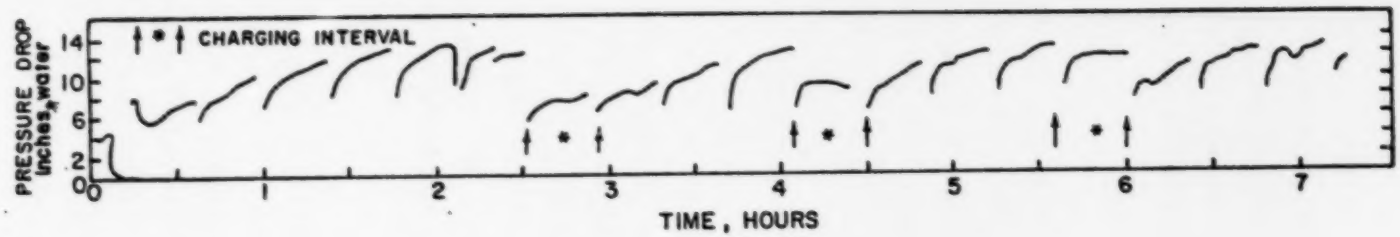

Figure 11. Filter pressure drop-time relationship for bronze fume filtration with reverse flow cleaning

Conclusions

The brass foundry field test demonstrated the value of the mobile fabric filter system for studying various fabric filter parameters with real industrial aerosols. Fabric filtration options that could not be investigated on the full scale system were conveniently investigated on the mobile system while most measurements including those for efficiency were simplified.

The pulse jet cleaning tests suggest that the fine metal oxide fume from a secondary brass smelter (mainly zinc oxide) can be efficiently filtered (~ 99.8 percent) with Nomex felt bags at a cloth velocity of 8 ft/min. Average filter pressure drop was maintained near 5 inches of water by using 80 ft^3/min(STP) of compressed air per 1000 ft^2 of filter area (equivalent to 10 ft^3(STP) of compressed air per 1000 ft^3 of gas filtered). It should be noted that the reported compressed air consumption for many industrial processes is often lower, ranging from 5 to 30 ft^3/min(STP).[10,11,12] On the other hand, the related filtration requirements are less severe. In the present situation, however, time did not allow investigation of the feasibility of changing pulse jet parameters or filtration velocity so as to reduce compressed air volumes (i.e., operating costs). The filter bags showed no signs of plugging or blinding after 28 hours in use. The life span of Nomex bags in this type of operation, of course, cannot be determined from short period tests.

Several mechanical shake cleaning options that could not be evaluated on the plant fabric filter were tested on the mobile system. Operating parameters were conveniently changed on the mobile system and collection efficiency was measured. Collection efficiency ranged from 99.84 to 99.95 percent, and the results serve as a useful guide to the expected efficiency of a well maintained full scale filter system operated in a similar manner. The specific dust fabric resistance coefficient

$K_2 \left(\frac{\text{in. } H_2O/\text{ft/min}}{\text{lb/ft}^2} \right)$ as calculated for various periods throughout the mechanical shake cleaning tests ranged from 150 to 300, indicating that a lower filtration velocity, 1 to 2 ft/min would produce more reasonable pressure drop results.

The reverse flow cleaning tests were too brief to judge the effectiveness for brass fume filtration. However, the collapsing of highly tensioned glass bags has proven successful in primary smelting operations at air to cloth ratios of 0.5 to 1.5 ft/min.

FIELD TESTS AT A HOT MIX ASPHALT PLANT

Background

Hot mix asphalt plants are recognized as one of the largest sources of fine particulates.[14] Although there are many individual sources of particulate emissions at a hot mix asphalt plant, including significant fugitive dust sources, the largest individual source is the rotary dryer used to dry and heat the aggregate before it is mixed with the asphalt. A 300 ton/hour dryer, if uncontrolled, will emit 6.75 tons/hour based on an emission factor of 45 lb/ton.[8] However, virtually all plants use at least a simple cyclone to recover some of the dust emitted from the dryer. The primary control device, usually a cyclone or multicyclone installation, may have a design efficiency of 60 to 90 percent and can be expected to reduce the dust concentration from 10-40 grains/ft^3 to 1-24 grains/ft^3. Federal regulations for new hot mix asphalt plants limit emissions to 0.04 grains/dscf.[9] To meet this Federal standard, and in some cases the more demanding local and state standards, new plants will need an overall collection efficiency of 99.7 to 99.9 percent and will use fabric filters or nigh energy wet scrubbers.

Process Description

Figure 12 is a schematic diagram of the hot mix asphalt plant dryer at the field test location. Aggregates of different size and sand are first conveyed to a gas-fired rotary dryer followed by elevation of the dried product to the hot screens where it is classified into several size fractions and stored in the hot bins. When a batch is required, certain amounts of each size aggregate are fed to the weigh hopper and blended with asphalt. Exhaust gases from the rotary dryer, hot screens, hot bins, and elevators are precleaned by a multiple cyclone before filtration with a pulse jet unit. The dust collected by the cyclone is conveyed to the hot screens and added to the final asphalt mix. Dust collected by the fabric filter is conveyed by water to a settling pond. The multicyclone dust collector was a Western Precipitator Company model 9VGR10, size 90-9, manufactured in 1969, containing 90 9-inch diameter cyclone tubes. The asphalt plant fabric filter, manufactured by Standard Havens, used pulse jet cleaning and 8-foot long by 7-inch diameter Nomex bags.[15] At the time of the field test, the fabric filter had just been placed in operation.

The rotary dryer was not operated continuously during the field testing period because of the lack of demand for asphalt on cold days. This sporadic operation caused some problems in operating the mobile system. At normal capacity, the gas-fired rotary dryer dried about 300 tons/hour. The exhaust gas flow from the fabric filter was 51,000 ft^3/min at 220°F.

Aerosol Properties and Particulate Sampling Procedures

The average inlet dust concentration entering the mobile fabric filter, 15 grains/ft^3(STP), was determined from the gas flow rate and the amount of dust collected by the fabric filter. The dust collected by the filter was continuously dumped by the rotary dust valve and easily weighed, since about 1800 grams were collected every 10 minutes.

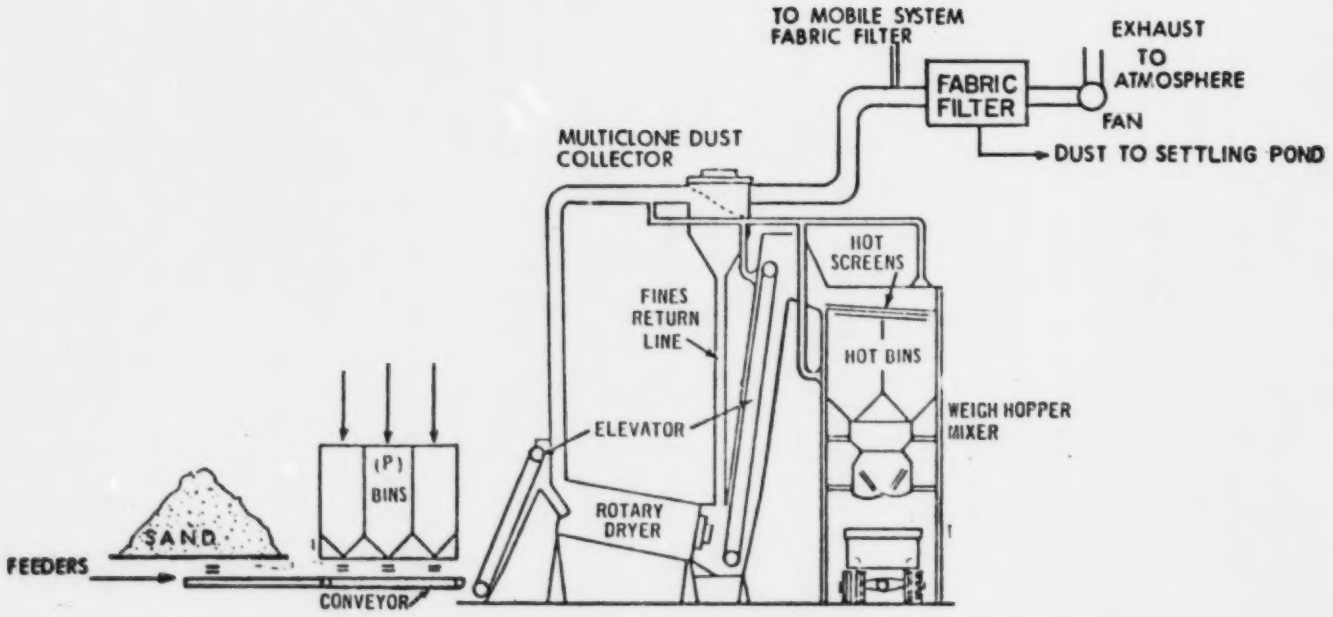

Figure 12. Schematic diagram of hot mix asphalt plant

The particle size distribution of the dust entering the mobile filter system was determined at various times during the field test. A Brink cascade impactor* was used to fractionate the aerosol by size. Samples were extracted by 1/4-inch diameter stainless steel probes with appropriate nozzles for isokinetic sampling. Each probe was approximately 5 inches long with a 90° elbow. Because the inlet dust concentration was 15 grains/ft^3(STP), sampling time even with the low flow rate Brink impactor was necessarily less than 1 minute. Longer sampling times could not be used as the upper stages of the Brink impactor would have been over loaded. In addition, the small nozzles needed for isokinetic sampling tended to plug.

Figure 13 shows the average inlet particle size distributions as determined by eight Brink impactor measurements. The use of a 90° elbow, the large particle size, and the low flow rate of the Brink impactor combined to cause the large inlet probe losses. Consequently, these losses averaged 43 percent of the total sample. These losses were apparently the result of gravitational settling and centrifugation in the elbow. A theoretical analysis indicated that 15 percent of the 8-micron particles and lesser amounts of the smaller particles may have been lost in the probes. Therefore, probe losses were included with the dust caught on the top stage of the Brink impactor. The data in Figure 13 show a mass median diameter greater 10 microns, 12-15 microns, and a standard deviation of 4.3.

The particle size properties of the dust collected by the mobile fabric filter and the plant cyclone were also analyzed. The size properties of the dust collected by the cyclone based upon a sieve analysis are presented in Figure 14. Although a sieve analysis cannot be compared to impactor measurements, as agglomerate often fail to redisperse, the

*Monsanto Enviro-Chem Systems, Inc., 800 North Lindbergh Blvd., St. Louis, Mo. 63166

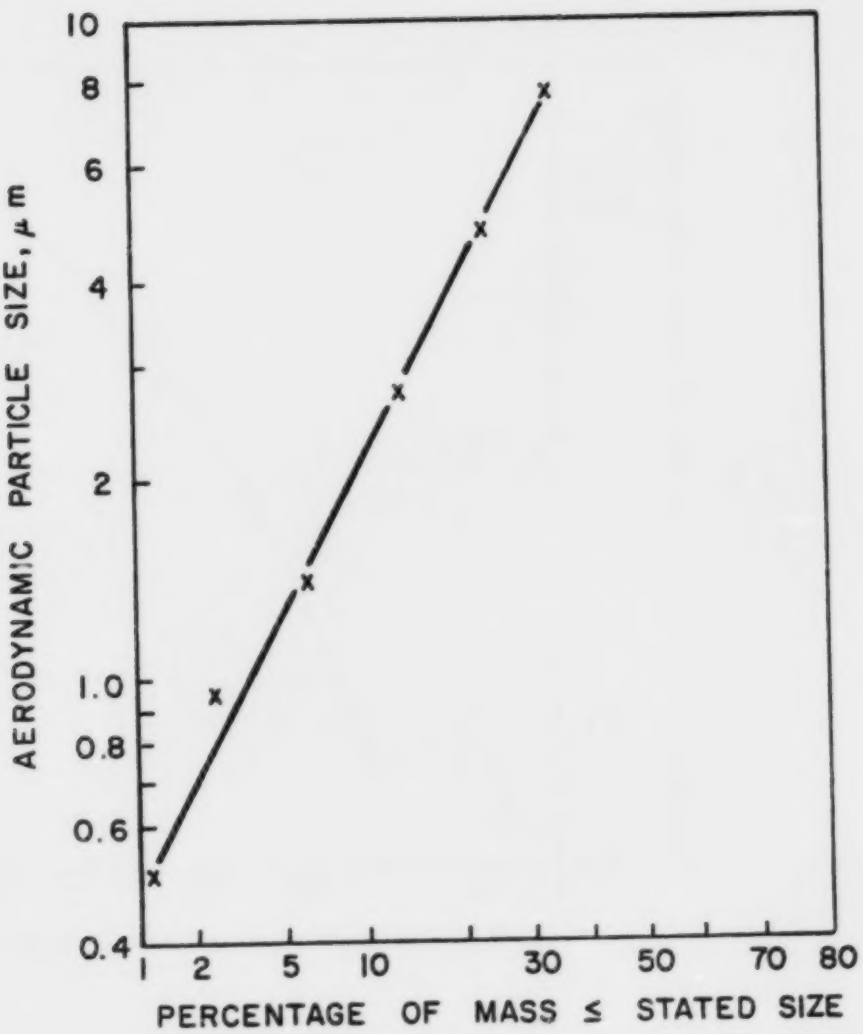

Figure 13. Hot mix asphalt plant mobile filter inlet cumulative particle size distribution as determined by Brink cascade impactor, 8-sample average

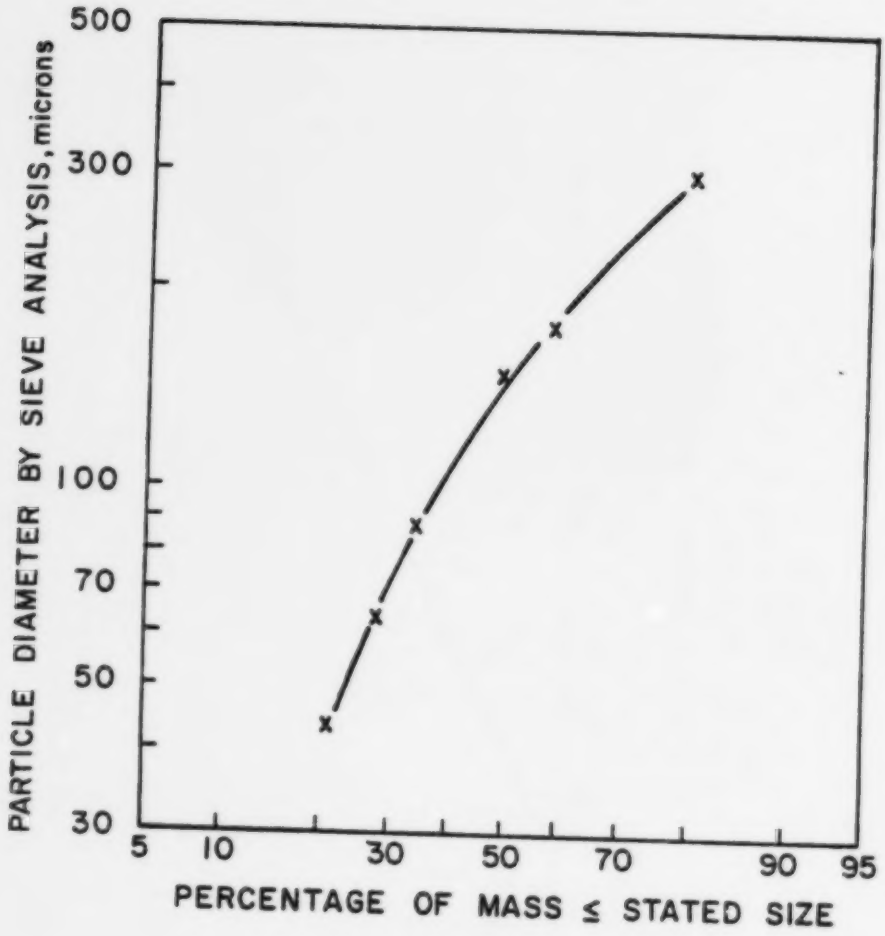

Figure 14. Particle size of dust collected by hot mix asphalt plant cyclone

results in Figure 14 do demonstrate the very large size of the dust collected by the cyclone. The results show a mass median diameter of 150 microns with 85 percent of the cyclone collected dust greater than 44 microns. Dust collected by the fabric filter was first put through a 44-micron sieve and then the remainder was analyzed with a Coulter Counter. The Coulter Counter results, as presented in Figure 15, show reasonable agreement with the impactor data except for the small sizes. Small particles may have agglomerated on the filter or in the hopper, and therefore measured as larger particles by the Coulter Counter. The large amount of material greater than 44 microns that reached the fabric filter suggests that the multiple 9-inch diameter cyclones were not operating at design efficiency. Nine-inch diameter cyclones should collect over 98 percent of the particles above 44 microns and since the concentration at the fabric filter (greater than 44 microns) was 5 grains/ft^3(STP), the inlet concentration to the cyclone above 44 microns would have had to be 250 grains/ft^3(STP). Also the measured concentration at the fabric filter and the emission factor for an asphalt plant dryer suggest an overall collection efficiency of approximately 60 percent for the plant cyclone.

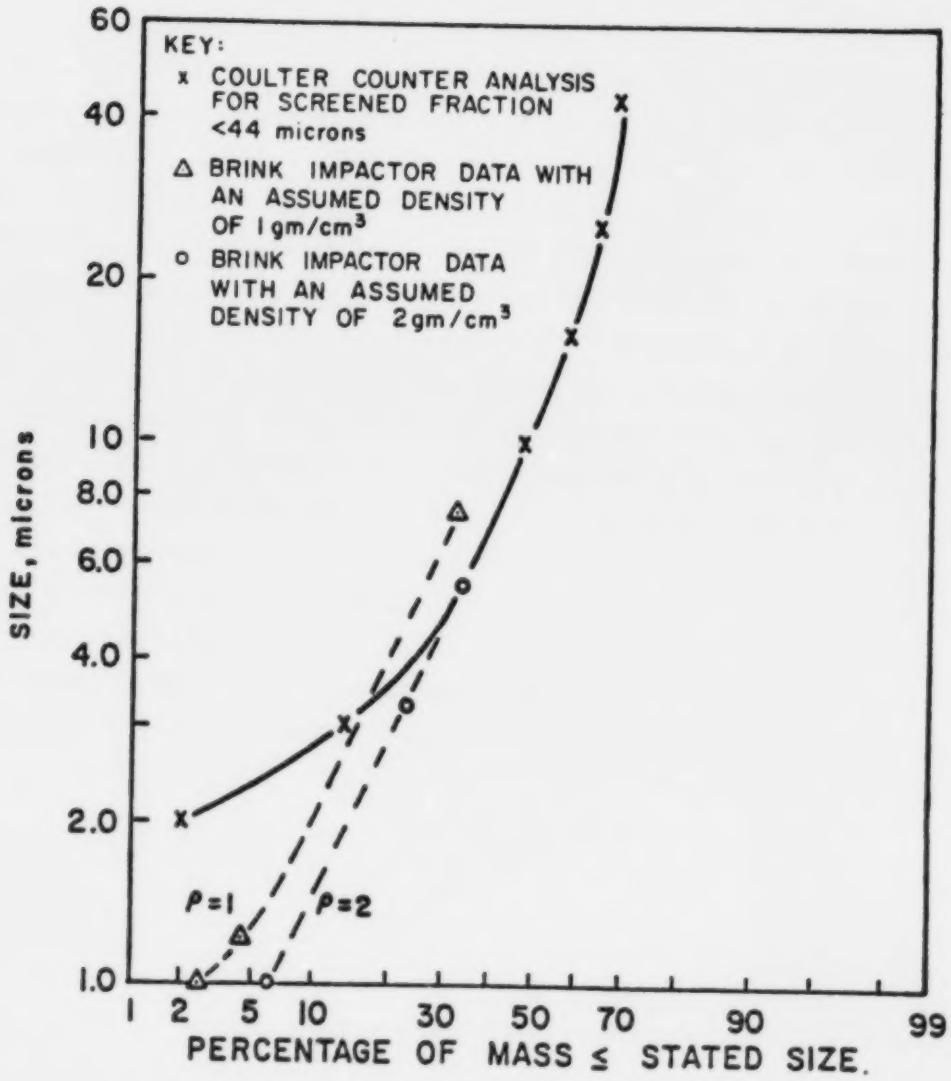

Figure 15. Particle size of dust collected by mobile fabric filter at hot mix asphalt plant as measured by Coulter Counter

Pulse-Jet System Operating and Cleaning Parameters

Pulse jet cleaning alone was used for the asphalt plant field test due to the high inlet dust concentration. Five Nomex felt bags were used, each 4 feet long and 4-1/2 inches in diameter. Filtration was performed on the outside of the bags with wire cages inside the bags for support. Venturis were used in the top of the bags. Filtration velocity averaged 8 ft/min at 250°F through a cloth area of 23.6 ft^2 for a total flow of 188 ft^3/min. Pulse supply pressure was 100 psig, with a pulse duration of 0.1 seconds. The interval between pulses was 0.4 minutes, and the total time to clean all five bags was 2 minutes. Principal filtration parameters for hot mix asphalt plant field test are summarized in Table 6.

Results of Field Measurements

Filter Pressure Drop - During the first test, different cleaning cycles were briefly evaluated in order to determine an effective operating cycle. A pulse supply pressure of 100 psig, a pulse duration of 0.1 seconds, and a 0.4-minute interval between pulses were chosen. The filter pressure drop versus time for the first test is shown in Figure 16. The high pressure drop during the first 3-1/4 hours was apparently caused by reentrainment of dust from the hopper. After 3-1/4 hours, the hopper (see Figure 17) was filled with dust to the level of the inlet pipe because the rotary dust valve was plugged with wet dust. As a result, large quantities of dust were reentrained and conveyed to the filter bags which led to excessive resistance. The mobile system was restarted after the hopper was manually emptied and the rotary dust valve was cleaned. During the last 1-3/4 hours, the inlet dust concentration averaged 12 grains/ft^3 (STP), and the filter pressure drop was fairly constant at an average of 2.8 inches of water.

Figure 18 shows the fabric filter pressure drop versus time for Tests 2, 3, 4, and 5. Start-up problems with the pulse system caused the high

Table 6. PRINCIPAL FILTRATION PARAMETERS FOR HOT MIX ASPHALT PLANT FIELD TEST

Bag Characteristics	
Material	Nomex felt
Weight, oz/yd^2	16
Length ft	4
Diameter, in	4½
Filter Area (Effective) ft^2	23.6
	Menardi Southern Augusta, Georgia
Part No.	17563
Cleaning Parameters	
Number of bags	5
Pulse frequency, min^{-1}	2.5
Cycle time, min	2
Pulse duration,[a] sec	0.1
Pulse supply pressure, psig	100
Compressed air consumption $ft^3/min/1000\ ft^2$ [b]	50
Filtration Conditions	
Air-to-cloth ratios ft/min	7.2 - 8
Gas flow, ft/min	169 - 188
Temperature, ^oF	220
Inlet dust concentration, grain/ft^3 (STP)	15
Inlet dust size,[c] microns	12 - 15

[a]Electrical signal to valve. True valve open time was 0.15 seconds.

[b]Standard cubic feet per minute of compressed air per 1000 square feet of filter area. About 0.46 ft^3/pulse.

[c]Aerodynamic mass median diameter

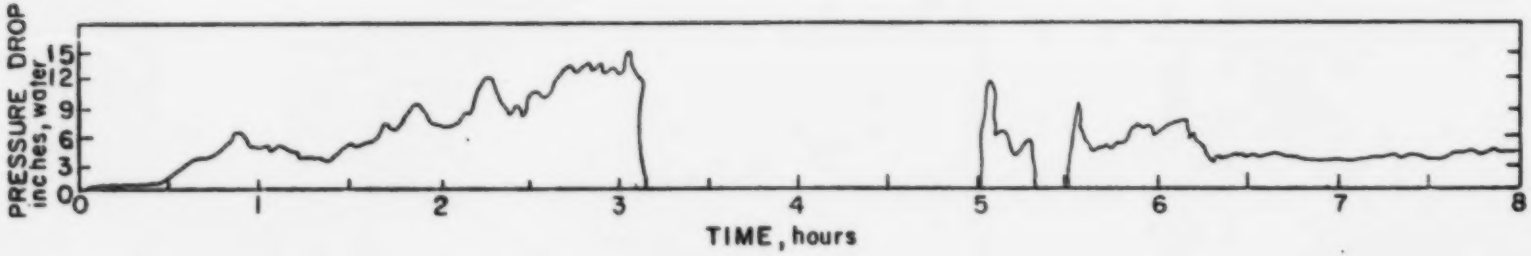

Figure 16. Filter pressure drop versus time, hot mix asphalt plant, Test 1

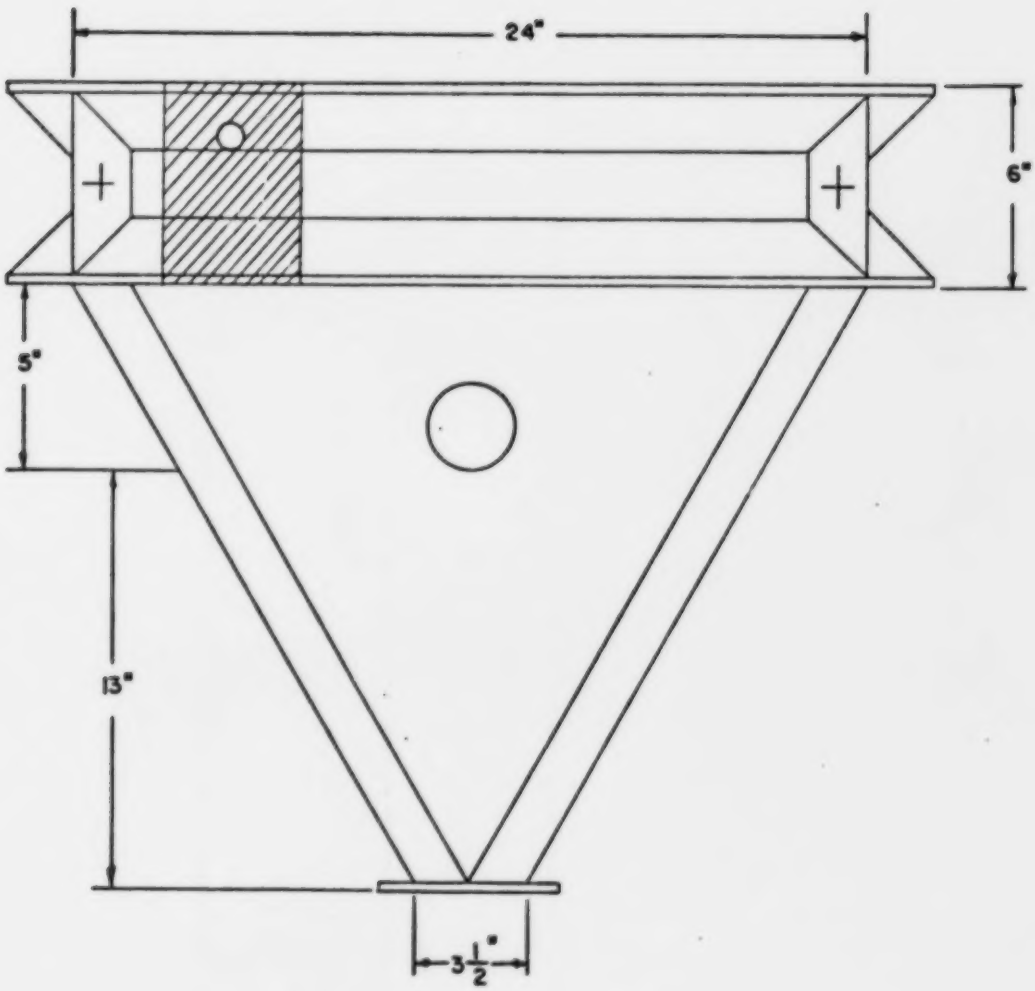

Figure 17. Mobile fabric filter unit hopper

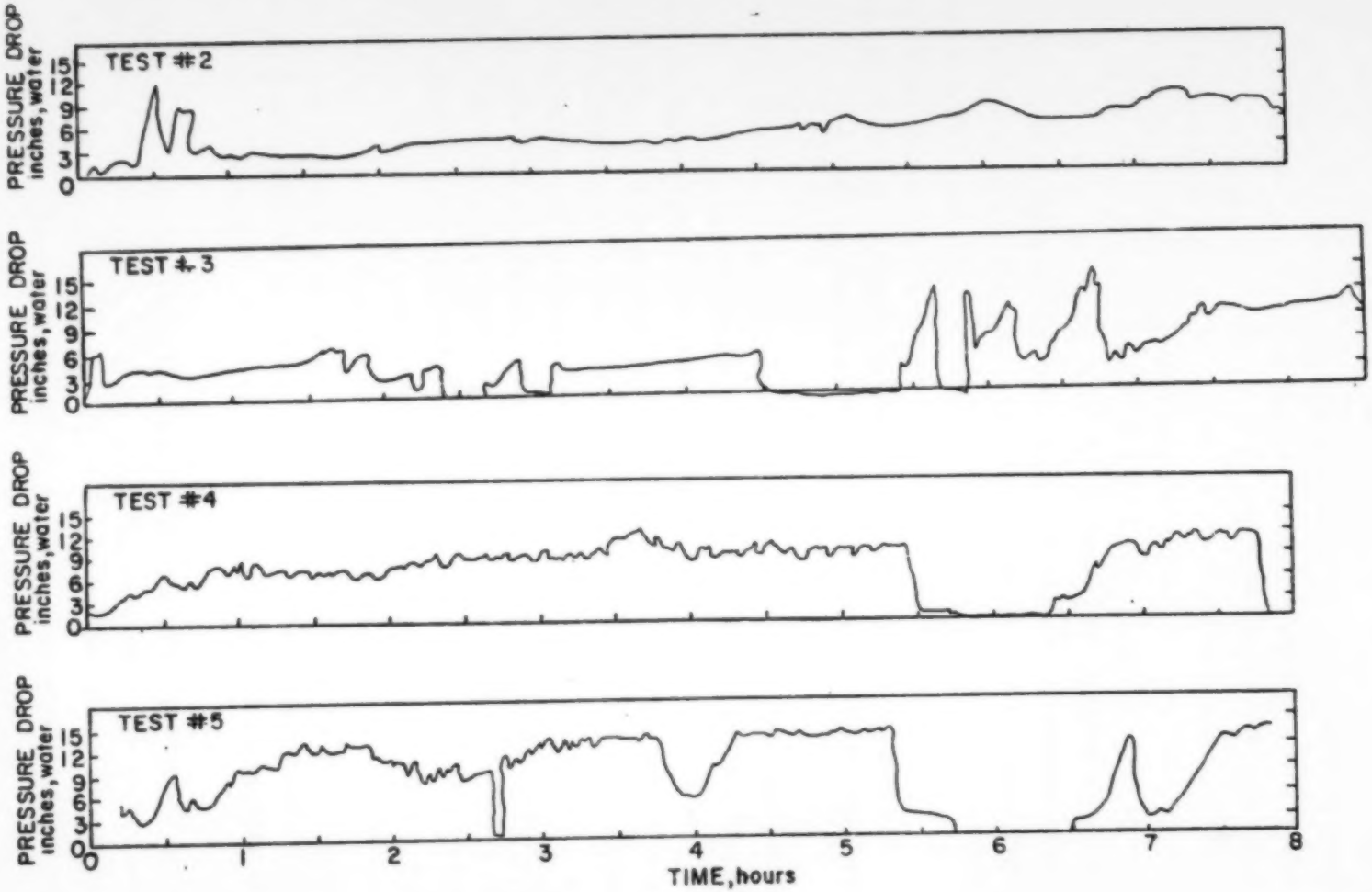

Figure 18. Filter pressure drop versus time, hot mix asphalt plant, Tests 2, 3, 4, and 5

pressure drop during the first hour of Test 2. The pressure drop returned to 2.8 inches of water as soon as the pulse system was operating properly. During the remainder of the 8-hour test, the filter pressure drop rose very gradually from 2.8 inches of water to 8 inches of water. Average inlet dust concentration was 15 grains/ft^3 (STP), as determined from the dust collected in the hopper over 25 intervals of 10 to 30 minutes. At total of 132 pounds of dust was collected. Although individual hopper samples indicated inlet concentrations from 12 to 18 grains/ft^3 (STP), averages over 1-hour periods were all close to 15 grains/ft^3 (STP). Therefore, the rising filter pressure drop was not caused by a change in inlet dust concentration. Since the filter had only been operated for 8 hours prior to this test, it is possible that the rise in filter pressure drop was simply due to equilibration of the new fabric.

During the third test, the rotary dryer was frequently shut down due to limited product demand (periods of zero pressure drop in Figure 18). When the dryer was not operating, the mobile fabric filter system operation was stopped. As in the previous test, the inlet dust concentration averaged 15 grains/ft^3 (STP). The filter pressure drop fluctuated widely due to shutdowns of the rotary dryer, but generally increased as the test progressed. During the first 2 hours, the average pressure drop was 3.5 inches of water while during the last 2 hours, the pressure drop averaged 8 inches of water. At 5.6 hours into the test, when the mobile filter system was being restarted after a rotary dryer shutdown, the pressure drop rose very rapidly. Very little dust was being removed from the bags as evidenced by the small amount of dust collected in the hopper during this period. Apparently a moisture problem associated with restarting the system resulted in very poor cleaning.

During the fourth test, the filter pressure drop continued to gradually rise. Inlet dust concentration again averaged 15 grains/ft^3 (STP). After only about 2 hours, the filter pressure drop was 7 inches of water, a much more rapid increase than observed in the previous tests. During the

remaining 6 hours, the filter pressure drop was near 8 inches of water. After this test, one might have concluded that after 24 hours of operation; i.e., 2 hours into Test 4, the new filter bags had reached an equilibrium condition.

However, the filter pressure drop during the fifth test, as shown in Figure 18, was higher than all previous tests. The inlet dust concentration during the fifth test was 16 grains/ft^3 (STP), only about 6 percent higher than the previous tests. Filtration velocity was 10 percent lower than the previous tests. After 2 hours the filter pressure drop was 9 inches of water. Towards the latter half of the fifth test, the filter pressure drop rose to 12 inches of water. At about 5-1/2 hours into Test 5, the filtration velocity was reduced by a factor of 1.42 for a brief period, causing an immediate decrease in filter pressure drop by a factor of 2.8. At the end of the test series, the bags were pulse jet cleaned for 6 minutes with no flow through the bags. After the above cleaning sequence, 3675 grams of dust were removed from the hopper, indicating that 158 grams/ft^2 were removed from the bags. When the fan was restarted, the filter pressure drop was 2 inches of water at 7 ft/min filtration velocity. Results of the pulse jet cleaning tests are summarized in Table 7.

Several factors might have caused the high pressure drop results. Moisture was a potential and at times a real problem. The gas temperature was 220°F, with a dew point of about 125°F, while the ambient temperature was about 40°F. After the first test, the rotary dryer, the plant fabric filter, and the mobile system filter were preheated before the aggregate feed was started. All components of the mobile system were insulated, and the inlet ducting was also heated during all tests. Reentrainment of dust from the hopper, due to the high inlet velocity, may have contributed to the high filter pressure drop. Reduction of the filtration velocity by a factor of 1.4 caused the filter pressure drop to decline by a factor of 2.8, indicating that for the specific test condition the pressure drop was

Table 7. PULSE JET CLEANING PERFORMANCE SUMMARY, HOT MIX ASPHALT PLANT FIELD TEST[a]

Parameters	Test 2[b]	Test 3	Test 4	Test 5
Filtration velocity, ft/min	8	8	7.5	7.2
Average filter pressure drop,[c] inches water	4.6	5.6	7.4	10.6
Inlet particle size,[d] microns	12-15	12-15	12-15	12-15
Average inlet concentration, grains/ft^3, STP	14.9	15.5	15.3	16.1
Average outlet concentration, grains/ft^3, STP	0.029	0.015	0.017	0.035
Number of outlet samples	3	3	3	1
Outlet sampling times, hrs	0.6, 0.6, 2.2	0.3, 0.4, 0.5	0.5, 1, 4	4
Average penetration,[e] percent	0.18	0.10	0.13	0.23

[a]Bag characteristics, cleaning parameters and test conditions were the same for all tests and were summarized in Table 6.

[b]Test 1 was an exploratory test used to determine effective operating cycle.

[c]Filter pressure drop varied widely during each test.

[d]Mass median aerodynamic diameter. Composite value for all tests

[e]Determined from inlet and outlet concentrations during specific time periods.

proportional to the velocity cubed. Therefore, it appears that filter pressure drop performance would have been sharply improved by lowering the filtration velocity from 8 ft/min to 5.6 ft/min.

Collection Efficiency - Effluent concentrations were determined over periods of 35 minutes and 2 to 4 hours from glass fiber filter samples and Andersen impactor* samples, respectively. Ten effluent samples, seven glass fiber filters and three Andersen impactors, were taken during the last four tests. The Andersen impactor samples were expected to be used for characterization of the effluent particle size but due to an assembly problem the results could only be used for total mass concentrations. Effluent concentration varied between 7×10^{-3} and 40×10^{-3} grains/ft^3 (STP). Inlet concentrations during the effluent sampling periods were determined from the gas flow rate and the dust collected by the fabric filter as previously described. Inlet concentrations ranged from 10-20 grains/ft^3 (STP) with an average of 15 grains/ft^3 (STP). Percent penetration varied between 0.05 and 0.25 percent with an average of 0.14 percent (99.86 percent efficiency). A correlation between filter pressure drop and effluent concentration or penetration was not apparent. Collection efficiency results have been summarized in Table 7.

Inlet Particle Size Results - A Brink cascade impactor was used to determine the inlet particle size distribution in the range 0.25 to 8 microns. A summary of these results, as well as some analysis of the larger particles, has been presented in the aerosol properties section. Results of each Brink impactor sample are presented in Figures 19, 20, and 21. Each sample covers only a very short period, about 1 minute. The results show a fairly constant particle size distribution. The dashed line in each figure shows the average of all Brink impactor runs. The results show that the differences in filter performance cannot be attributed to changes in particle size distribution.

*Andersen 2000 Inc., P.O. Box 20769, Atlanta, Ga. 30320

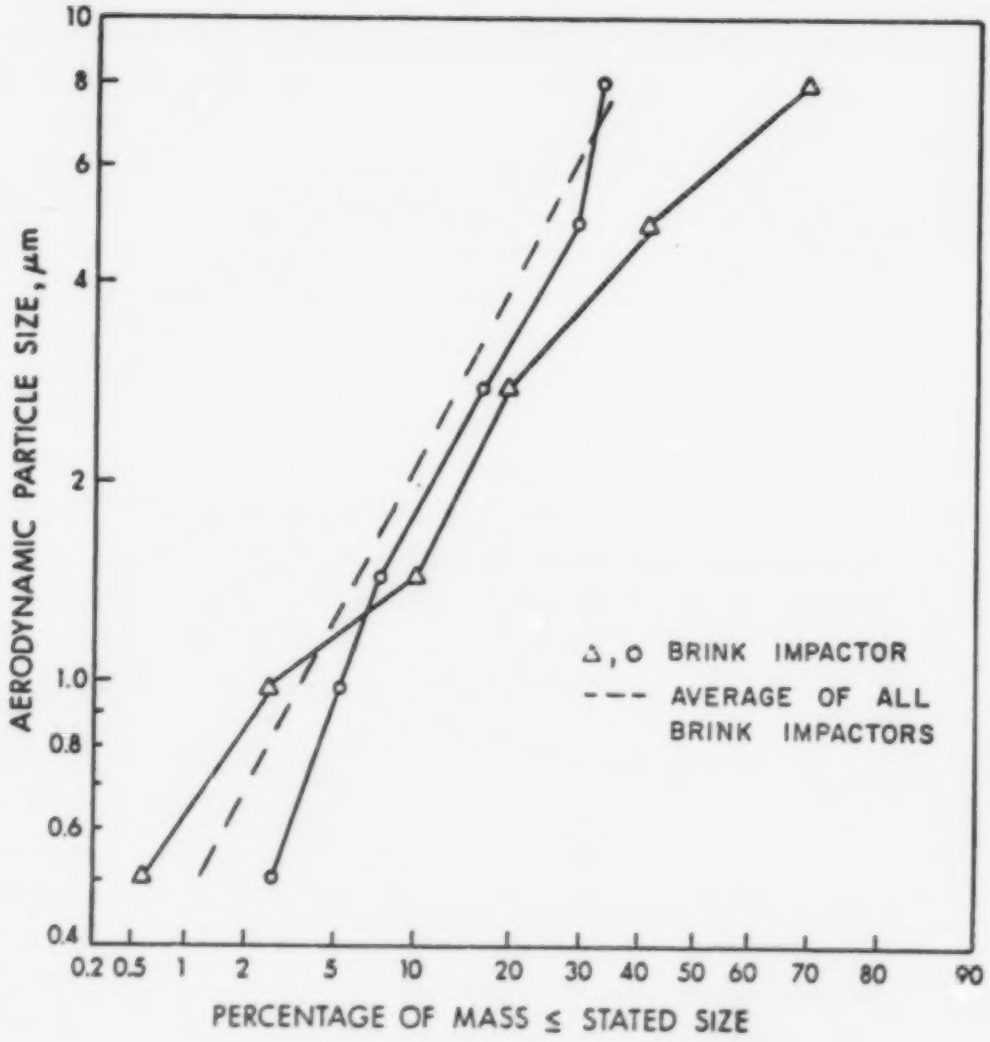

Figure 19. Inlet cumulative particle size distribution, Test 3, as determined from Brink impactor samples

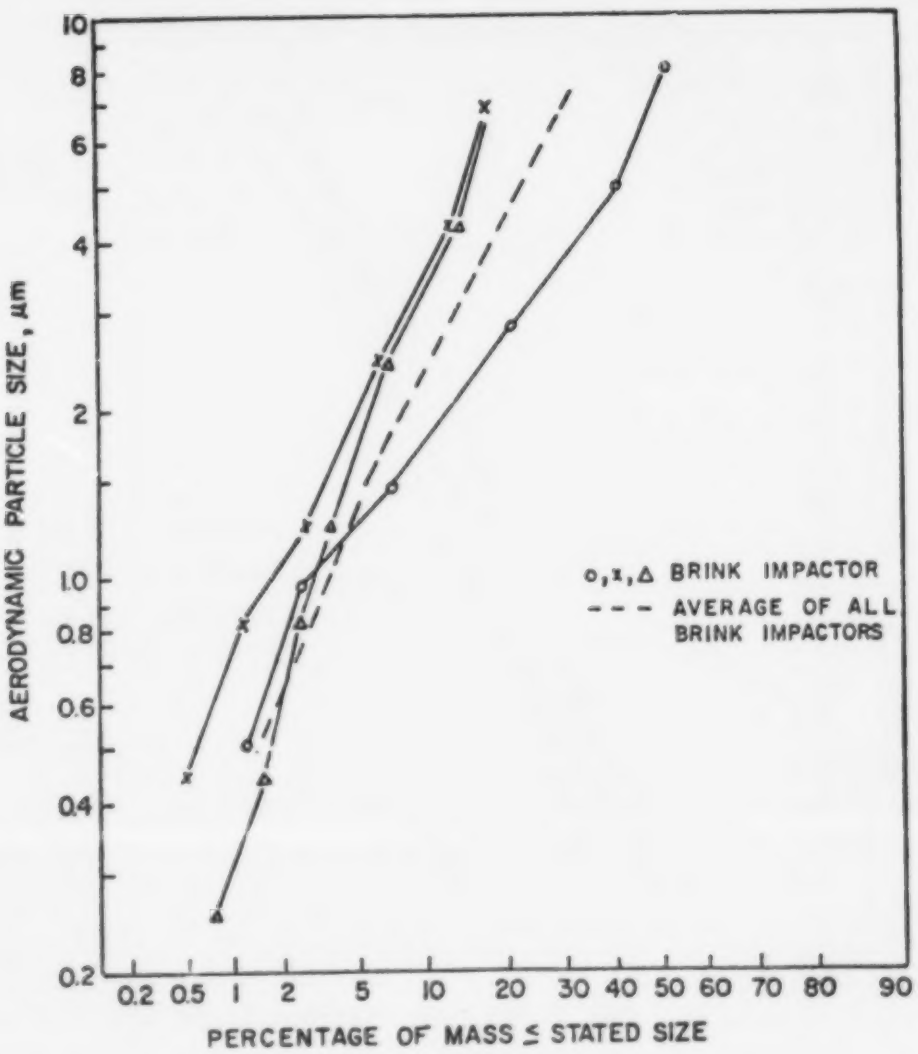

Figure 20. Inlet cumulative particle size distribution, Test 4, as determined from Brink impactor samples

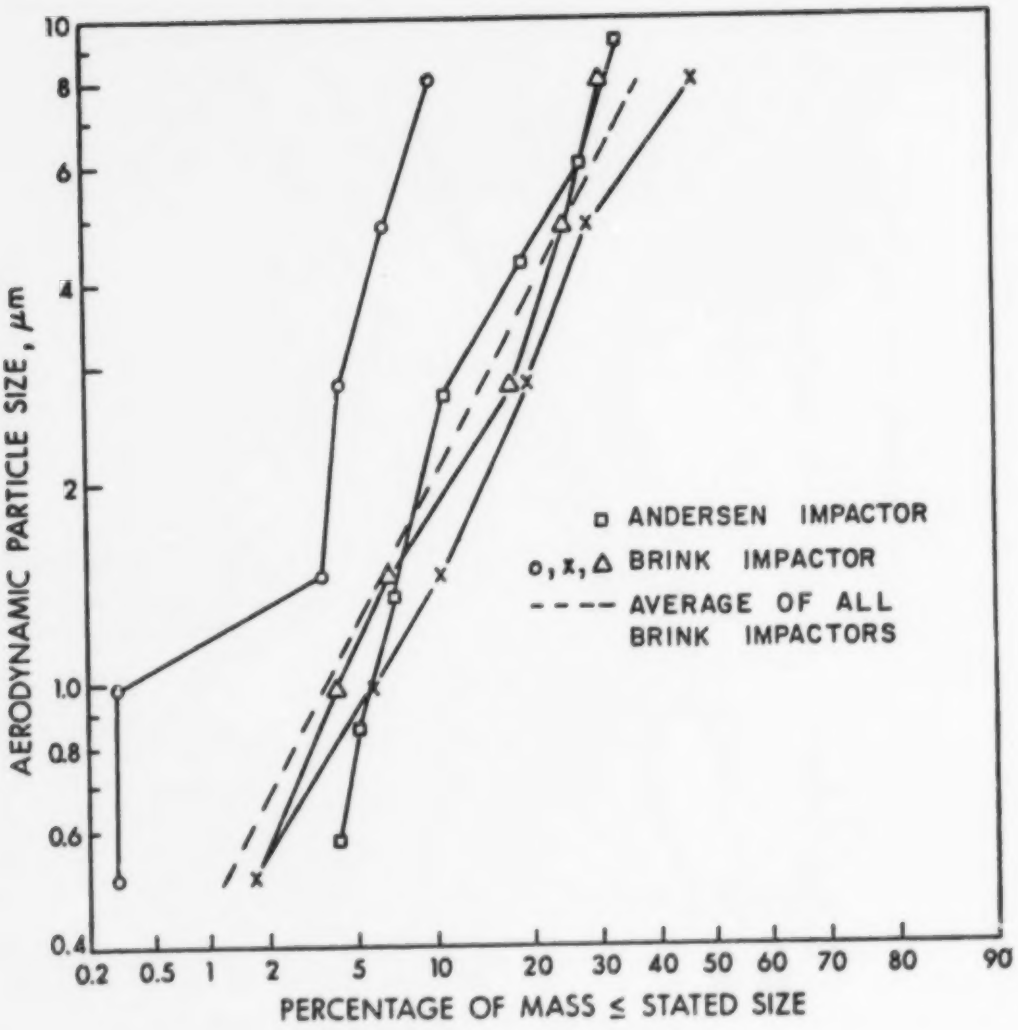

Figure 21. Inlet cumulative particle size distribution, Test 5, as determined from Brink and Andersen impactor samples

Plant Fabric Filter System - During the field test, the operation of the plant fabric filter system was observed. The plant filter operated without a visible plume and typically at a pressure drop of 2 to 3 inches of water, never exceeding 3 inches of water. When the rotary dryer was shut down, the pressure drop fell below 2 inches of water. Filtration velocity through the plant fabric filter was 6.5 ft/min based on a measured gas flow of 51,000 ft^3/min. The baghouse contained 39 rows of bags with 14 bags in each row. The Nomex felt Bags were 8 feet long and 7-inch diameter. One of the 39 rows was cleaned every 8 seconds for a total cycle time of 5.2 minutes. Pulse supply pressure was 100 psig with a duration of 0.1 seconds and a 1/2-inch diameter orifice above each bag. Compressed air consumption by the plant fabric filter was reported to be 8 to 13 ft^3/min/1000 ft^2.[15] The plant filter system used a top inlet and a baffle to redirect the gas flow. The gas flow was directed downward toward the hopper and around the side of the bags. The downward gas flow would remove some of the large particles entering the baghouse, as about 30 percent of the inlet dust was greater than 40 microns. In addition, the gas flow around the sides of the bags would reduce the upward gas velocity in the baghouse. Collection efficiency of the plant fabric filter was not measured.

Conclusions

The pressure drop performance of the mobile fabric filter system was poor in the selected operating mode. Compressed air consumption was fairly high, 50 ft^3/min/1000 ft^2, and the filter pressure drop was high, 11 to 12 inches of water. Although the filter system was operated at a lower filtration velocity (6.5 ft/min versus 8 ft/min) for only 15 minutes, it appears that the pressure drop performance was sharply improved. Bakke[16] has shown, in laboratory tests, that the pressure drop performance of a pulse jet cleaned fabric filter in certain specific cases is very strongly dependent on the filtration velocity. For instance, in one case, Bakke showed that a reduction in filtration velocity from

5 ft/min to 4 ft/min caused a reduction in filter pressure drop from 8 inches of water to 2 inches of water. The brief reduction in filtration velocity during this field test indicated that the filter pressure drop was proportional to the velocity cubed for the specific test conditions and filter housing geometry. The continuous rise in filter pressure drop throughout the field test may have been caused by moisture problems.

The pressure drop performance of the plant fabric filter system was better than the mobile system. The plant filter operated at a 2- to 3-inch water pressure drop and had a reported compressed air consumption of 8 to 13 $ft^3/min/1000\ ft^2$ versus an 11- to 12-inch water pressure drop and a compressed air consumption of 50 $ft^3/min/1000\ ft^2$ for the mobile system. It appears that the lower filtration velocity was the primary reason for the lower pressure drop, although geometry may have also been an important factor.

Effluent concentration from the mobile fabric filter averaged about 0.02 grain/dscf, indicating that a similiar, well maintained full scale system could meet the applicable new source performance standard of 0.04 grains/dscf.

FIELD TESTS AT A COAL-FIRED POWER PLANT

Background

The large amount of particulate pollutants emitted by coal-fired electric power plants, 3,100,000 tons per year,[14] is well known and needs no further discussion in this report. Electrostatic precipitators are used to achieve collection efficiencies greater than 95 percent, and in a very few cases, as high as 99.5 percent. However, the installed cost of an electrostatic precipitator rises sharply as the design efficiency is increased. In recent years there has been an increased interest in the use of fabric filters to control particulate emissions

from coal-fired boilers. At least two coal-fired power plants are using fabric filters.[17] Collection efficiency at one power plant is reported to be 99.84 percent with an average effluent concentration of 0.003 grains/dscf.[18]

Fly ash emissions may be collected by fabric filters using low pressure reverse flow, mechanical shaking or pulse jet cleaning. Currently, one coal-fired power plant is using a combination of low pressure reverse flow and mechanical shaking[20] while another is using reverse flow.[19] Both plants use woven glass bags with a fiber finish, teflon, silicone and graphite in one case and teflon and silicone only in the other case, to prevent fiber-fiber abrasion. A pilot scale investigation of reverse air cleaning using felted materials is currently being conducted.[20] In addition, a pulse jet cleaned filter using teflon felt bags and designed to handle a few hundred thousand ft^3/min is scheduled to be installed on a coal-fired industrial boiler.[21] During this field test, the mobile system was operated in the mechanical shake cleaning mode with woven glass bags.

Process Description

The field test was conducted during July 1974 at a coal-fired electric power plant using two cyclone-fired boilers with a combined electric generation capacity of 500 MW. Particulate emissions before control from cyclone-fired boilers are generally only 15 percent of the emissions from other power plant boilers burning coal with the same ash content. In addition, cyclone-type boilers produce emissions with a smaller particle size.[8]

A test stream, about 66 ft^3/min, from the exhause duct of the smaller boiler (120 MW capacity) was filtered by the mobile system. The test stream was extracted from the duct immediately before the electrostatic precipitator. The coal received during the 2 months preceding the field test had been analyzed by plant personnel as follows:

	May	June
Moisture, %	3.3	3.8
Ash, %	7.0	7.2
Volatile, %	34.3	37.3
Fixed carbon, %	55.5	51.7
Sulfur, %	3.5	2.1
Btu/pound	13,400	13,600

The mobile unit was operated 8 hours during the day for 3 consecutive days while the boiler was operated at capacity. While the mobile system was operating, the boiler burned 45 tons of coal per hour.

System Operating and Cleaning Parameters

Mechanical shake cleaning was used during the entire test. Three glass bags, each 6 feet long and 5-9/16-inch diameter with a loop at the top and a cuff at the bottom, were used. Filtration was through the inside of the bags with upward flow. The glass fibers had a teflon-silicone-graphite coating. Filtration velocity during this test series was 2.7 ft/min at 270 to 290°F. Except for the last 3 hours of the field test, the same cleaning cycle was used. There were 22 minutes of filtration followed by a 15-second pause, 55 seconds of shake cleaning and a 45-second pause to allow the dust to settle. Shaking frequency was 7 cps at an amplitude of 7/8 inch, giving a shaker arm acceleration of 4.4 g's. Static bag tension throughout the field test was 1-1/2 pounds. Inlet fly ash concentration averaged 0.7 grain/ft^3 (STP) with a mass median aerodynamic diameter of 5 microns and a standard deviation of about 3.3. Cleaning parameters and test conditions are summarized in Table 8.

The test stream was extracted through a 3.5-foot probe with an inside diameter of 2.2 inches at approximately isokinetic conditions. The probe was inserted through the top of a 7-foot high by 19-foot wide

Table 8. MECHANICAL SHAKE CLEANING OPERATING PARAMETERS, COAL-FIRED POWER PLANT FIELD TEST

	Test 1
Bag Characteristics	
Material	Glass - Woven Filament
Weight, oz/yd^2	8.4
Weave	3 x 1 Twill
Thread Count	53 x 51
Clean Cloth Permeability[a]	45 - 60
Length, ft	6
Diameter, in	5-9/16
Number of Bags	3
Manufacturer	Globe Albany
Part No.	Q53-875
Cleaning Parameters	
Number of Compartments	1
Filter Cycle	
Filtering, min	22
Pause, min	0.25
Shaking, min	0.92
Dust Settling, min	0.75
Shaker Arm Amplitude, in	7/8
Shaker Arm Frequency, cps	7
Shaker Arm Acceleration,[b] g's	4.4
Static Tension, lb	1.75
Average Filtration Conditions	
Air to Cloth Ratio, ft/min	2.7
Gas Flow, ft^3/min	66
Temperature ^oF	280
Inlet Dust Concentration, grains/ft^3 (STP)	0.7
Inlet Duct Size,[c] microns	5

[a] Gas flow in ft^3/min per ft^2 of cloth area at a pressure drop of 1/2 inch water

[b] Acceleration = $4\pi^2$ (frequency)^2 (amplitude)

[c] Aerodynamic mass median diameter

horizontal duct at a point about 5 feet from one side. There was an elbow in the plant duct about 3 feet before the mobile system probe, but there was no other possible sampling location. About 100 feet of heated and insulated piping was used to reach the mobile system. Temperature at the mobile filter entrance was maintained between 270 and 290°F while in the plant duct the temperature was about 300°F. Velocity through the mobile system piping was 2350 ft/min, resulting in a loss of some large particles.

Each day the mobile system was started up and operated in the following manner. First the mobile system ducting was disconnected about 3 feet before the fabric filter. The fan, located after the fabric filter as depicted in Figure 22, was then started. The system was operated in a warm-up mode for 30 to 45 minutes with a 150,000 Btu/hr space heater used to heat the inlet gas to 350° - 400°F. Next the piping was reconnected, the shutoff valve near the probe was opened, and filtration was started. Filtration temperature at the start was 160°F but rose to 250°F within 10 to 15 minutes. The filter housing, exit ducting, and fan were insulated with 3-1/2-inch thick fiberglass. In addition the inlet ducting was heated.

Results of Field Measurements

Filter Pressure Drop - Pressure drop results for the first test are presented in Figure 23. The results show a fairly rapid increase in filter pressure drop through the first four cycles. The average filter filter pressure drop stabilized at 4.8 inches of water after the fifth cycle.

Figure 24 presents the filter pressure drop during a single filtration cycle. The linear portion of the curve, representing cake-like filtration, began after 9 minutes. Based on an average inlet concentration of

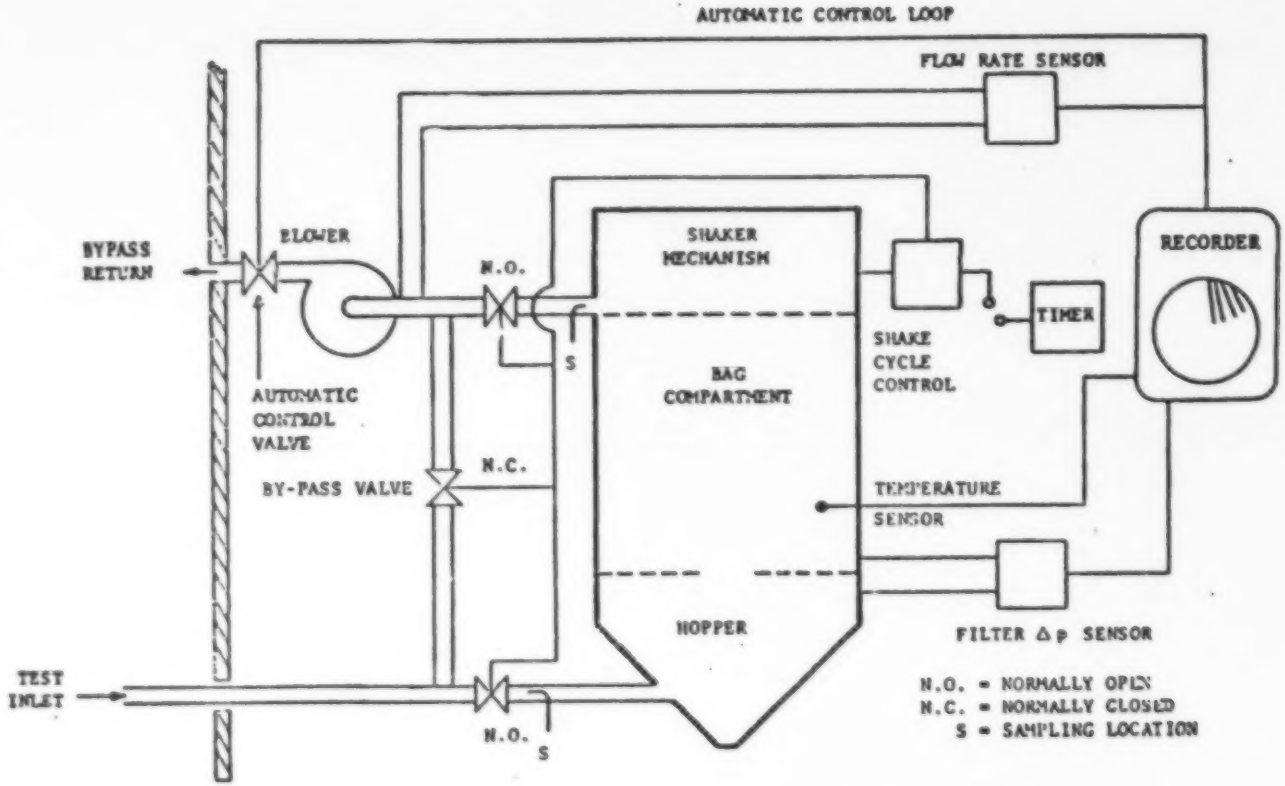

Figure 22. Mechanical shaking system control arrangement

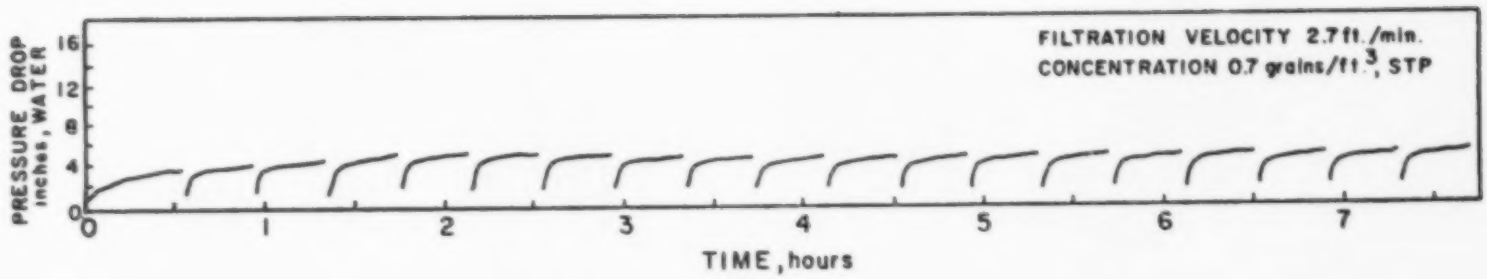

Figure 23. Mobile system filter pressure drop versus time at a coal-fired power plant, Test 1

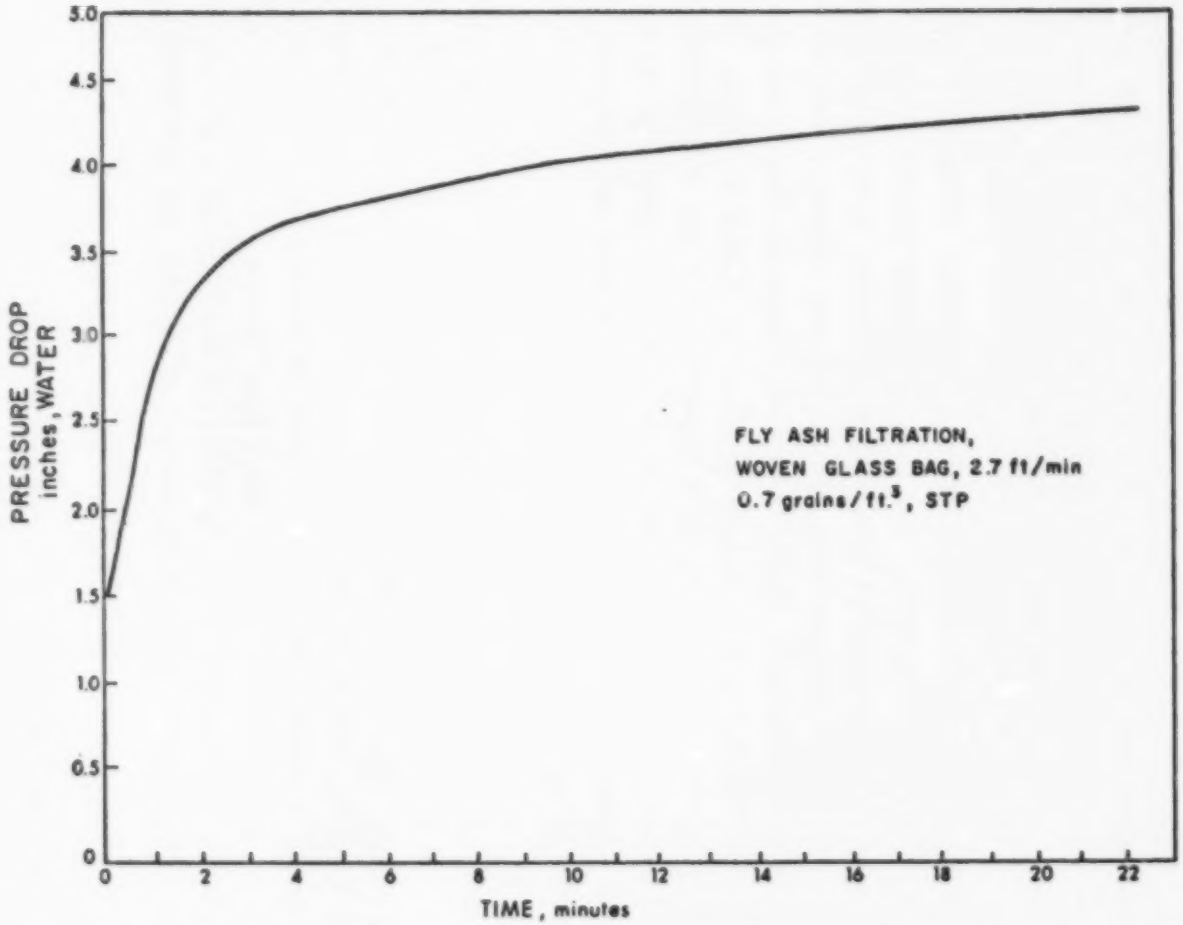

Figure 24. Filter pressure drop versus time for a single filtration cycle, coal-fired power plant field test

0.7 grain/ft^3 (STP), (0.5 grain/ft^3 at 280°F), the specific cake-fabric resistance was calculated to be 28 in. H_2O/ft/min per lb ft^2.

The second test was a repeat of the first test. During the test the filter pressure drop rose very gradually and averaging 5.2 inches of water during the test compared to 4.8 inches of water during the first test.

Figure 25 shows the fabric filter pressure drop versus time during the third test. At the end of the first cycle the clutches that connect the shaker arms to the motor failed to operate as a valve in the compressed air supply was closed. Clearly a negligible amount of dust was removed by simple deflation. Pressure drop continued to rise during the first half of the third test, averaging about 5.4 inches of water. During the last 2-1/2 hours, a 40-minute filtration cycle was used instead of the previous 22-minute cycle. Filter pressure drop rose about as expected, and the specific cake-fabric resistance was near the previously calculated value of 28.

After the last complete cycle, the bags were thoroughly cleaned by opening the access windows and hand shaking which removed 260 grams of dust. The dust remaining on the filter after hand shaking was not determined. The average amount of dust removed from the bags during a single cleaning cycle, 47 grams, was calculated from the average inlet concentration and the total number of cycles. The amount of dust on the filter at the initiation of normal cleaning was at least 307 grams (260 plus 47 grams) indicating that less than 15 percent (47 grams) was removed per cleaning cycle.

Collection Efficiency - Effluent concentration was determined by isokinetic sampling with collection by glass fiber filters and Andersen impactors. Samples were taken over periods ranging from 40 to 350 minutes with each sample automatically shut off while the filter was being cleaned. Sampling was automatically restarted at the same instant that filtration was resumed in order to collect any puffs of dust. A total

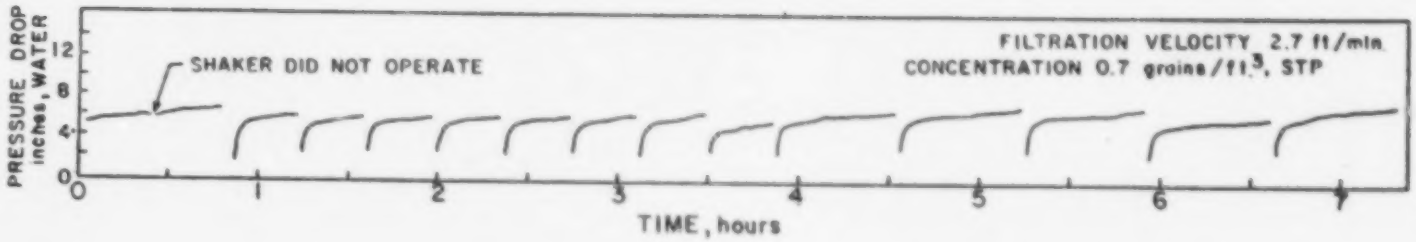

Figure 25. Filter pressure drop versus time at a coal-fired power plant, Test 3

of six samples were taken and the results are listed in Table 9. The time-weighted average concentration of the effluent samples was 0.0027 grain/ft^3(STP).

Table 9. FILTER EFFLUENT SAMPLES, COAL-FIRED POWER PLANT FIELD TEST

Sample type	Sampling time (minutes)	Concentration (grain/ft^3, STP)
Glass fiber	40	0.0043
Impactor	235	0.0040
Impactor	350	0.0016
Glass fiber	80	0.0022
Glass fiber	80	0.00088
Glass fiber	125	0.0041

Inlet mass concentration was determined from five glass fiber filter samples, each taken over a 60-minute period. The measured inlet concentrations were 0.40, 1.1, 0.57, 0.8, and 0.8 grains/ft^3 (STP), with an average value of 0.7 grain/ft^3 (STP). Plant personnel reported that the inlet concentration to the electrostatic precipitator was about 0.7 grain/ft^3. Average mass penetration was 0.38 percent and the collection efficiency was 99.62 percent. The last three inlet samples were taken during the same period as the last three outlet samples. Calculation of the average percent penetration from this last group of samples yields a value of 0.33 percent. Fabric filter performance is summarized in Table 10.

Particle Size Measurements - Andersen impactors were used to determine inlet and outlet particle size distribution. Ten-inch long straight probes were inserted through elbows in the 2-1/2 inch diameter system ducting. The straight probes eleminated the common problem of probe losses. Impactors were of course heated and sampling was at isokinetic flow rates. Figures 26 and 27 show that the inlet and outlet particle size distributions were very similar.

Table 10. MECHANICAL SHAKE CLEANING PERFORMANCE SUMMARY, COAL-FIRED POWER PLANT FIELD TEST[a]

Parameters	Test 1	Test 2	Test 3
Filtration velocity, ft/min	2.7	2.7	2.7
Average filter pressure drop, inches water	4.8	5.2	5.4, 6.2[a]
Inlet particle size,[b] microns	5	5	5
Average inlet concentration,[c] grains/ft^3, STP	0.7	0.7	0.7
Average outlet concentration, grains/ft^3, STP	0.0040	0.0016	0.0024
Number of outlet samples[d]	2	1	3
Average penetration, percent	0.57	0.23	0.34

[a]Filter pressure drop averaged 6.2 inches of water during the last half of the third test, when a longer cycle was used.

[b]Mass median aerodynamic diameter, average of all inlet size data.

[c]Inlet concentration was assumed to be constant throughout the field test. A total of five 1-hour samples were taken.

[d]Individual results were presented in Table 9.

Particle penetration by size was calculated from the Andersen impactor data. Because upstream and downstream impactors were identical and operated at the same flow rates, the sizing intervals were the same. An average inlet and outlet concentration in each size interval was calculated and then the penetration was determined. The results are listed in Table 11. The results show an unexplainable minimum penetration between 0.43 and 0.64 microns. If the data below 0.64 microns are combined, then the penetration in each size interval is similar.

Conclusions

Pressure drop across the mobile fabric filter averaged about 5.4 inches of water after 20 hours of testing at a filtration velocity of 2.7 fpm. The specific cake-fabric resistance coefficiency (K) was 28 in. H_2O/ft/min per lb/ft^2. Spaite et al.[22] reported a K value of 7 - 10 for fly

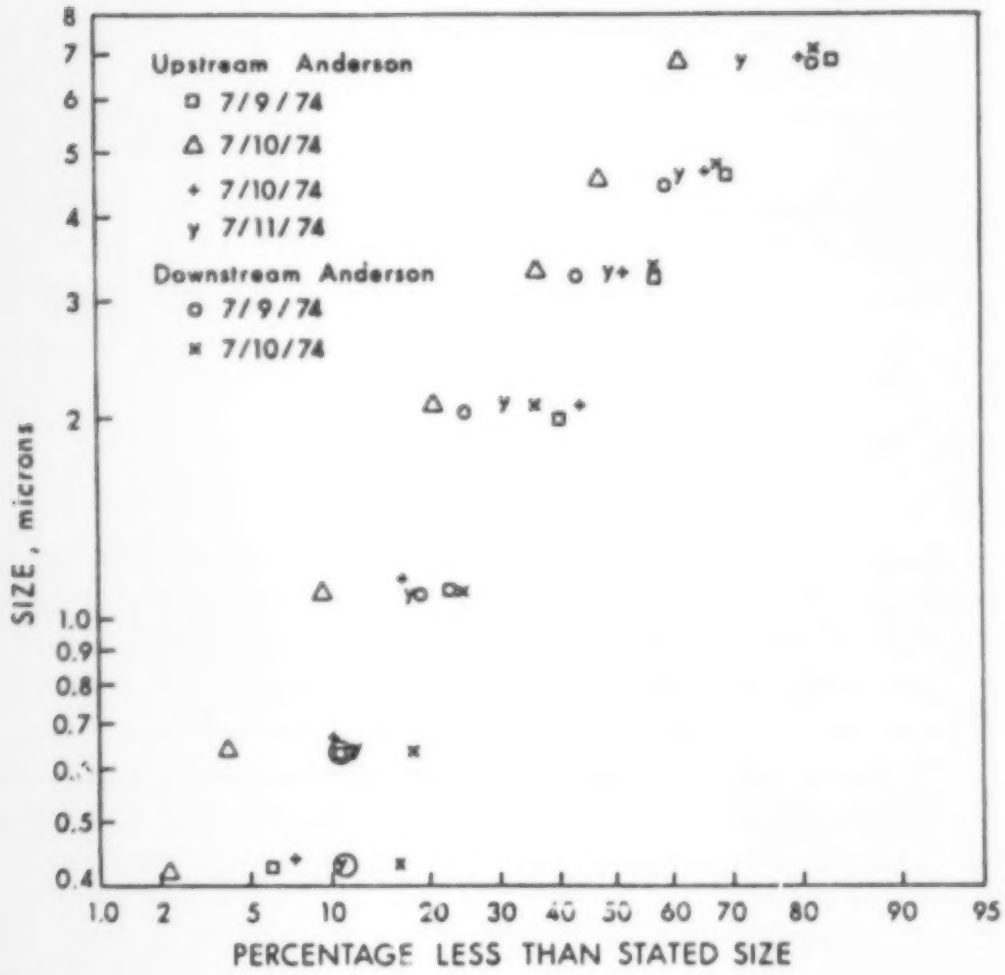

Figure 26. Fly ash cumulative particle size distribution, assumed particle density of 2 gm/cm^3

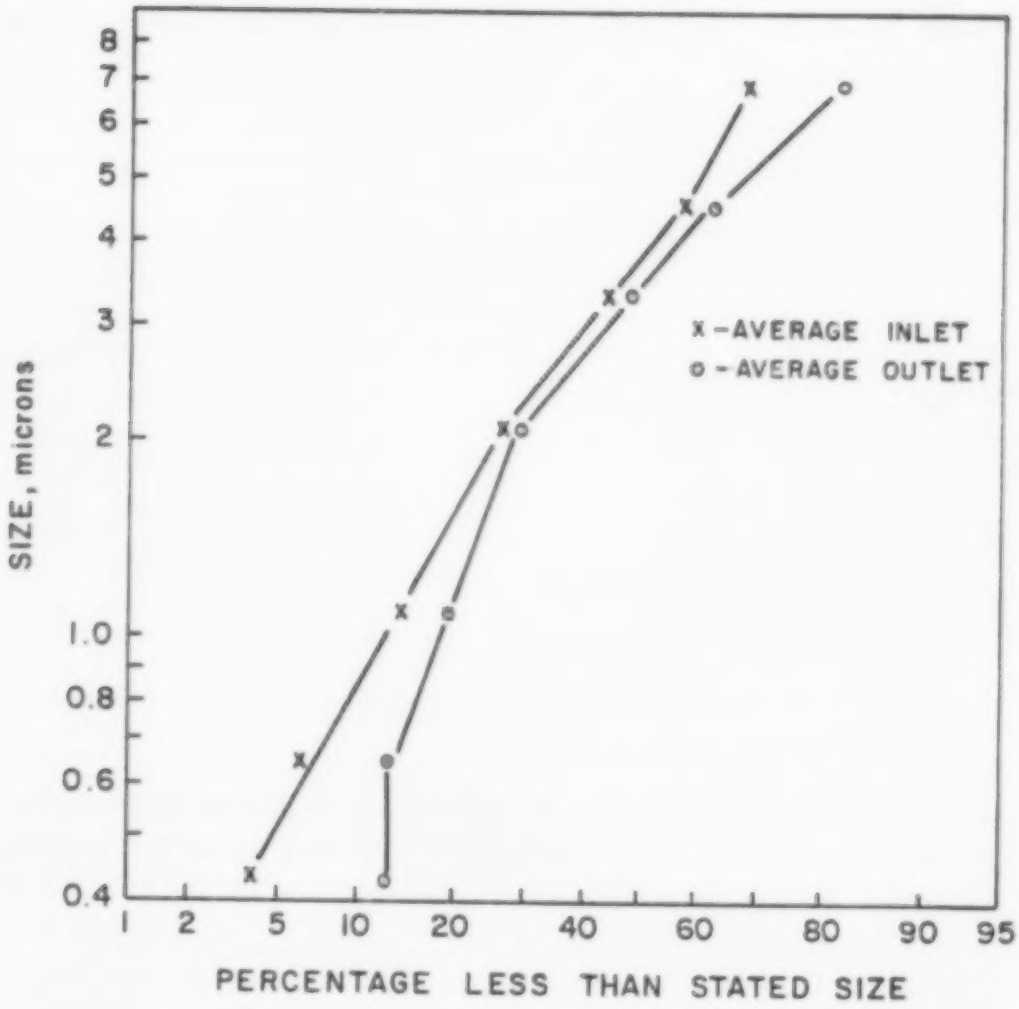

Figure 27. Fly ash average cumulative particle size distribution, assumed particle density of 2 gm/cm^3

ash filtration (pulverized coal-fired power plant) by glass bags at a filtration velocity of 2.3 ft/min. Dennis and Wilder[5] reported a specific cake-fabric resistance coefficient of 14 for laboratory filtration of fly ash (cyclone boiler) by woven dacron bags. While the results of the mobile system tests showed a higher cake-fabric resistance, this might be attributed to differences in particle size, fabric, and gas composition.

Table 11. PARTICLE SIZE DATA

Size interval microns[a]	Upstream concentration 10^{-3} grain/ft^3(STP)	Downstream concentration 10^{-3} grain/ft^3(STP)	Penetration %
> 11.0	94.4	0.370	0.39
6.9 - 11.0	57.0	0.132	0.23
4.6 - 6.9	75.0	0.558	0.74
3.3 - 4.6	71.1	0.413	0.58
2.1 - 3.3	89.4	0.495	0.55
1.1 - 2.1	71.1	0.269	0.38
0.64 - 1.1	37.9	0.180	0.48
0.43 - 0.64	13.7 } 36.4	0.014 } 0.358	0.09 } 0.98
< 0.43	22.7 }	0.346 }	1.52 }

[a]Density assumed to be 2 gm/cm^3.

The operating cycle used in this field test would not be desirable in an actual installation. A much longer time between cleaning would reduce fabric wear and take better advantage of the gradual rise in filter pressure drop during the linear portion of the pressure drop versus time curve (the low K value). If a longer cycle caused an unacceptable pressure drop then a reduction in filtration velocity, which would cause a sharp decrease in filter pressure drop, would be required.

The average effluent concentration of 0.0027 grain/dscf meets current and projected emission standards for coal-fired boilers. Fractional size penetration showed no large differences. Although theory predicts

increasing penetration as the particle size decreases to about 0.3 microns and then a decrease in penetration[23] as the size decreases further, this may not always occur in practice. Fabric filter theories are often based on the concept of direct penetration. However, emission from fabric filters may actually be a combination of factors as outlined below:

- Inlet dust that because of its small size, passes directly through the filter, usually in progressively smaller amounts as the filter pore structure becomes plugged.

- Dust that migrates through the filter by successive deposition and reentrainment under the combined effects of aerodynamic and mechanical (vibration) forces. Such dust penetration is often referred to as "seepage" in commercial parlance.

- Dust dislodged from the shaken fabric during cleaning that has penetrated to the clean air region. Resumption of air flow flushes out the clean air side of the system, often producing a visible puff of dust.

- Dust loosened during the cleaning process whose bonding to the fibers or interstitial dust structure is not sufficiently strong to resist the combined dislodging forces (aerodynamic and mechanical flexure) when system air flow is resumed.

Only emissions from the first source type would be directly related to the inlet concentration and size.

SERIES FILTRATION SHAKEDOWN TESTS

Background

The effluent concentration from a mechanical shake cleaned fabric filter generally decreases as the amount of dust on the filter increases. Effluent concentration may decrease by a factor ranging from 2 to 10^5 during a 30-minute filtration cycle. Dennis and Wilder[5] reported decreases in effluent concentration between 10^2 and 10^5 during a 30-minute filtration cycle, with the sharpest decrease during the first few minutes of filtration. Durham and Harrington[24] reported decreases in effluent number concentration (~ 1 - 25 micron particles) of up to 10^2 in the first 5 minutes of the filtration cycle with the magnitude of the decrease depending on the dust, fabric and humidity.

It should be possible to pass the effluent from a "just cleaned" bag into one or more previously cleaned bags, thereby providing a higher collection efficiency during the period, a few minutes, when the filter layer is being reconstructed. This could be done sequentially, such that at no time during the system operation would the effluent from a "just cleaned" bag be discharged directly to the stack. This approach, series filtration, should reduce particulate emissions without requiring less vigorous cleaning that invariably results in higher air handling costs.

Equipment Description

A flow diagram showing the basic components of the series filtration system as fabricated under this contract is presented in Figure 28. The operation of the system is automatically controlled by various timers as outlined in Table 12. The booster fan recirculates the effluent from a "just cleaned" bag back to the system inlet, mixing the returned effluent with the primary aerosol. This mixture is then filtered by all of the bags including the just cleaned bag. After a suitable period of

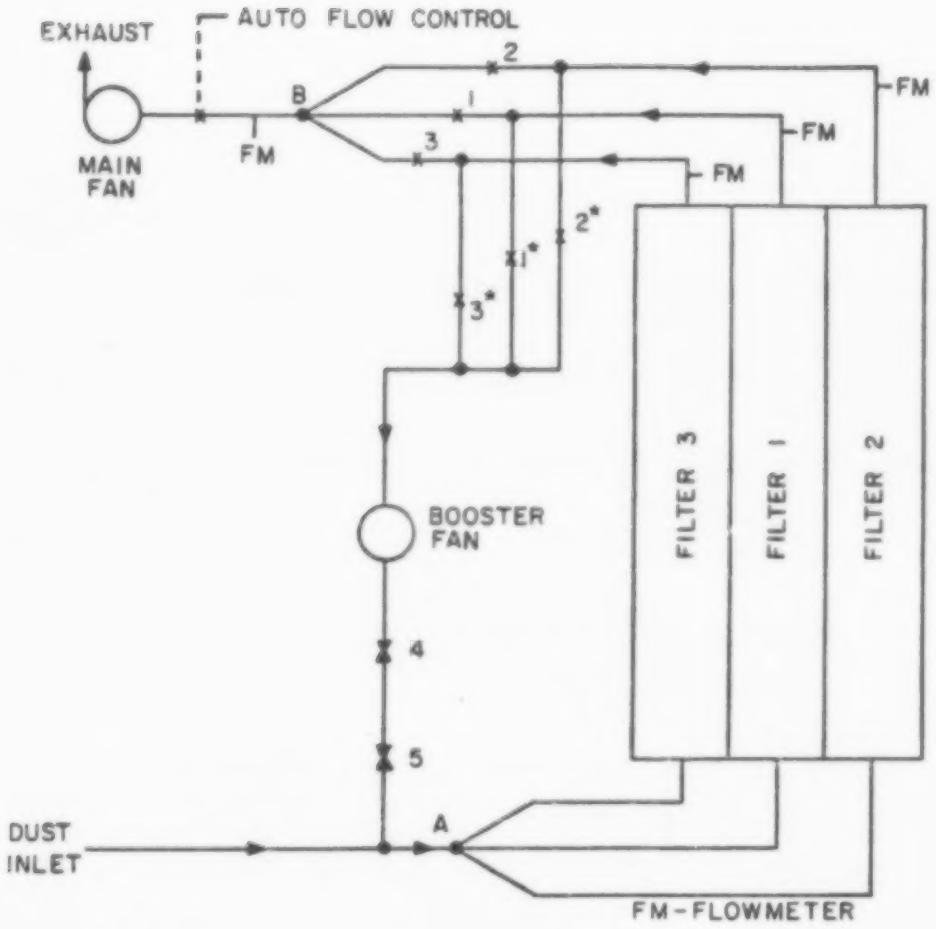

Figure 28. Series filtration flow diagram

Table 12. SERIES FILTRATION OPERATION[a]

I. All compartments on line - timer T_1 Range 3 - 60 minutes
   1, 2, 3 open
   1^*, 2^*, 3^*, 5 closed
   4 set manually for series flow

II. Short pause - timer T_2 range 0.25 - 5 minutes
   1 closes
   All others remain in position I

III. Shake - timer T_3 or T_4 range 1 - 150 seconds
   1 closed
   All others remain in position I

IV. Pause - timer T_5 range - 0.25 - 5 minutes
   Dust settles
   Valves same as III

V. Series fan starts - timer T_6 range 3 - 60 seconds
   Valves same as III

VI. Series filtration - timer T_7 - 0.25 - 5 minutes
   1^*, 2, 3, 5 open, fan on
   1, 2^*, 3^* closed

VII. Series filtration ends after T_7 minutes as 1^* and 5 close. After a short pause of 0.02 T_7 minutes, the series fan goes off, valve 1 opens and the system returns to Step 1. Steps I-VII are then repeated for second compartment with valves 2 and 2^* operating instead of 1 and 1^*.

[a]Series filtration flow diagram was presented in Figure 28.

series filtration, the just cleaned bag is placed in parallel with the others, to restore full system capacity. The flow through the just cleaned bag during series filtration is independent of the exhaust flow to the atmosphere and is manually controlled by a valve near the booster fan. The exhaust flow is automatically controlled at a constant flow. At no time is the effluent from a "just cleaned" bag exhausted to the atmosphere. Therefore, when one compartment is off-line for cleaning or series filtration the flow through the two on-line compartments must increase. A more detailed description of the series filtration system is presented in the Mobile Fabric Filter System Design Report.[4]

System Operating and Cleaning Parameters

A summary of system operating and cleaning parameters is presented in Table 13. The test aerosol consisted of redispersed fly ash and laboratory air. Fly ash was fed at a constant rate to a compressed air ejector which redispersed the particles. Previous tests[5] have shown that the redispersed fly ash has a mass median diameter of 8 microns with a standard deviation of 2. Relative humidity was estimated to be near 50 percent. Gas temperature was about 75°F. Inlet dust concentration was determined from the known gas flow and dust feed rates both of which were constant.

Three filter bags each 6 feet long and 5-9/16 inches in diameter with a loop at the top and a cuff at the bottom were used. The material was a 10 oz/yd^2 woven Nomex. No prior data on the change in effluent concentration with filter dust loading for this particular aerosol-fabric combination were available. The filter bags were cleaned by mechanical shaking at 6 cps, with a shaker arm amplitude of 7/8-inch. Acceleration of the shaker arm, an indication of the energy imparted to the fabric, was calculated to be 3.2 g's. Static bag tension was set at 1-1/2 pounds.

The system was operated as both a series filtration unit and a normal three compartment baghouse. The operations involved in series filtration

Table 13. MECHANICAL SHAKE CLEANING, SERIES FILTRATION, OPERATING AND CLEANING PARAMETERS

Bag characteristics	
Material	Nomex woven
Weight, oz/yd^2	10
Weave	2 x 2
Thread count	40 x 37
Clean-cloth permeability[a]	32
Length, ft	6
Diameter, in	5-9/16
Number of bags	3
Manufacture	Globe Albany
Part number	853
Basic cleaning parameters[b]	
Number of compartments	3
Shaker arm amplitude, in	7/8
Shaker arm frequency, cps	6
Shaker arm acceleration,[c] g's	3.2
Static tension, lb	1-1/2
Average filtration conditions	
Air-to-cloth ratio, ft/min	2
Gas flow, ft^3/min	50
Temperature, ^{o}F	75
Dust	Resuspended fly ash
Inlet concentration, grains/ft^3 (STP)	3
Inlet dust size,[d] microns	8

[a]Gas flow in ft^3/min/ft^2 of cloth area at a pressure drop of 1/2-inch water.

[b]Retails on the timing of the series filtration and normal three compartment operations are presented in Figure 28 and Tables

[c]Acceleration = 4 π^2 (frequency)^2 (amplitude).

[d]Mass median diameter for an assumed particle density of 2 gm/cm^3. Measured in a previous test series.[5]

have been described in detail in the previous section (Equipment Description). The timers controlling the operations were set as follows:

I. Timer T_1 - All compartments on line - 12 minutes.
II. Timer T_2 - Short pause - 0.25 minutes.
III. Timer T_4 - Shake - 60 seconds.
IV. Timer T_5 - Pause - 1 minute.
V. Timer T_6 - Series fan start - 10 seconds.
VI. Timer T_7 - Series filtration - 2 minutes.

The same times were used for the normal three compartment operation except the system cycled only through the first four steps as previously outlined in Figure 28 and Table 12.

Filtration velocity was a nominal 2.0 ft/min with all compartments on line and 3.0 ft/min with one compartment off-line. Actual filtration velocity in each compartment varied depending on how the total exhaust flow of 50 ft^3/min was divided among the three compartments. The filtration velocity through the just cleaned bag during series filtration was set at 2.8 ft/min.

Results

Filter Pressure Drop and Flow - The gas flow through each compartment was measured with an orifice meter having a 2-inch water pressure drop at 21 ft^3/min. Magnahelic gauges were used to measure the pressure drop across each compartment. In the present system, the flow division between the three compartments is a function of three parallel resistances between points A and B in Figure 28. Each resistance is composed of the following:

1. Inlet piping resistance
2. Filter resistance
3. Flow meter resistance
4. Outlet piping resistance

In commercial systems resistances 1, 3, and 4 would probably be insignificant compared to the filter resistance and each compartment operating in parallel would therefore have the same pressure drop. The orifice meters used in the series filtration system were designed to have a low pressure drop but still provide reliable data. However, the flow meter resistance at the flow rates used in these tests caused different pressure drops across the three parallel compartments.

Typical series filtration flow and pressure drop data are presented in Table 14. The system had been operating for a few hours before the data in Table 14 were recorded. The data at 46 minutes show flows of 22, 15, and 13 ft^3/min at pressure drops of 1.7, 3.0 and 3.0 inches of water respectively. If the flow meter resistance were not significant, the pressure drops would have all been identical and flow-through compartment number 1 would have been higher. Table 14 also shows that when a compartment was shut down for cleaning, the flow and filter pressure drop were zero as expected. Valves had to be adjusted to achieve complete sealing and, therefore, zero flow and pressure drop during cleaning. The data also show, as expected, that the compartment due to be cleaned has the lowest flow and highest pressure drop, and after cleaning the same compartment has the highest flow and lowest pressure drop. It is difficult to determine the average flow and pressure drop but looking at the data for all compartments filtering, the average total flow was 50 ft^3/min and the filter pressure drop was about 2.5 inches of water.

Collection Efficiency - As previously discussed the purpose of the series filtration system was to increase the overall collection efficiency compared to a normal three compartment system. Increased efficiency would be accomplished by preventing the direct discharge of dust from a "just cleaned" bag to the atmopshere. The dust emitted from a single bag during the first 2 minutes of a 30 minute filter cycle can vary from 13 to over 99 percent of the total emissions depending upon the dust-fabric combination.[5] Therefore, series filtration will not reduce emissions from certain dust fabric systems but may decrease emissions from other systems by factors exceeding 100.

Table 14. TYPICAL SERIES FILTRATION DATA

Time in filtering cycle (minutes)	Exhaust flow ft^3/min	Compartment No. 1		Compartment No. 2		Compartment No. 3		Comments
		Flow ft^3/min	Pressure drop in water	Flow ft^3/min	Pressure drop in water	Flow ft^3/min	Pressure drop in water	
0	49	23	1.7	13	3.4	13	3.2	All compartments filtering
5	51	23	2.1	14	3.7	14	3.4	
9	50	30	3.1	0	0	20	5.0	No. 2 being cleaned
10-12	47	28	3.0	23-22	1.0-1.4	19	4.8	Series filtration
13	50	18	3.1	22	1.6	10	2.9	All compartments filtering
20	50	19	2 3	20	2.2	11	3.2	
24	54	27	3.4	27	3.4	0	0	No. 3 being cleaned
25-27	49	24	3.4	25	3.6	24-23	1.7-2.6	Series filtration
29	50	16	2.4	16	2.5	18	2.2	All compartments filtering
37	50	17	2.6	17	2.75	16	2.7	
41	48	0	0	24	4.8	24	4.9	No. 1 being cleaned
43	46	23	1.4	23	4.7	23	4.6	Series filtration
46	50	22	1.7	15	3.0	13	3.0	All compartments filtering
56	49	21	2.2	15	3.3	13	3.3	
57	49	29	3.4	0	0	20	5.0	No. 2 being cleaned
59-61	46	27	3.4	24	1.5-2.0	19	4.8	Series filtration
62	50	17	2.4	21	2.0	12	3.2	All compartments filtering
68	49	24	4.0	25	3.9	0	0	No. 3 being cleaned
70	46	23	4.0	23	4.0	23	2.0	Series filtration
73	52	18	2.8	16	2.8	18	2.4	All compartments filtering
84	50	0	0	25	5.2	25	5.3	No. 1 being cleaned

Valid filter efficiency results were only obtained during the last day of shake-down testing. Inlet dust concentration was determined from the gas flow rate and the known dust feed rate. Outlet concentration was determined from samples collected on glass fiber filters. During series filtration two outlet samples were taken, one over a 1-hour period and another over a 2-hour period. Outlet concentrations were 0.000888 and 0.0017 grains/ft^3 (STP) and percent penetration was 0.029 and 0.057. On the same day the system was operated as a normal three compartment baghouse. Outlet concentrations from the three compartment system were 0.0017 and 0.0012 grains/ft^3 (STP) and percent penetration was 0.057 and 0.041. The samll difference between the outlet concentrations in the two operating modes and the short test duration prevented any conclusions regarding the effectiveness for the aerosol-fabric system.

A potential problem that was considered and eliminated was the possibility that inlet dust might leak from point A to point B (Figure 28) through valves 5 and 1^*, 2^*, or 3^*. The valves used were tested to have a very low leak rate when adjusted correctly, but a leak of 0.05 ft^3/min would cause an effluent concentration at point B of 0.003 grain/ft^3. Points A and B are both below atmospheric pressure, therefore by introducing a positive pressure between the two points (drilling a 1/8-inch hole between valves 4 and 5), the possibility of dust bypassing the filter was eliminated.

CHAPTER IV

LABORATORY INVESTIGATIONS

MECHANICAL SHAKE CLEANING

Objectives and Approach

Fabric filtration studies have shown that several factors relating to particle fabric interactions must be defined before one can design a filter system whose performance can be predicted with an acceptable degree of reliability. A major problem area is the penetration of fine particulates that appear to play a major role in atmospheric reactions and biological effects. Previous GCA measurements[5] have indicated that effluent mass concentration from mechanical shake cleaned filters may decrease by factors of 10^2 to 10^5 over a filtration cycle. In addition, the same measurements indicated that the effluent number concentration (particles $\geq$ 0.3 microns only) decreased by factors up to 10^4. Durham and Harrington[24] have reported similar results for certain dust, fabric, humidity combinations. Other investigations also suggest that the particulate emissions resulting from a specified dust/fabric system may show only a marginal dependence on the concentration of the inlet aerosol.[23,25]

Dennis[23] has suggested that the particulate emissions from a mechanical shake cleaned fabric filter can be attributed to some combination of the sources presented in Table 15.

Table 15. SOURCES OF PARTICLE PENETRATION THROUGH A MECHANICAL SHAKE CLEANED FABRIC FILTER

a.	Inlet dust that, because of its small size, passes directly through the filter, usually in progressively smaller amounts as the filter pore structure becomes plugged.
b.	Dust that migrates through the filter by successive deposition and reentrainment under the combined effects of aerodynamic and mechanical (vibrational) forces. Such dust penetration is often referred to as "seepage" in commercial parlance.
c.	Dust dislodged from the shaken fabric during cleaning that has penetrated to the clean air region. Resumption of air flow flushes out the clean air side of the system, often producing a visible puff of dust.
d.	Dust loosened during the cleaning process whose bonding to the fibers or interstitial dust structure is not sufficiently strong to resist the combined dislodging forces (aerodynamic and mechanical flexure) when sytem air flow is resumed.

The data presented in this section present the results of a series of tests which were conducted in order to determine, for a particular aerosol/fabric system, the relative importance of factors (a) and (b) combined and (c) and (d) individually. In order to accomplish this goal, the effect of filter dust holding on the mass and number concentration of the filter effluent, as a function of inlet aerosol concentration and size, was studied. In addition, short-term measurements, on the order of a few seconds, of the effluent mass and number concentration were made in order to study the relative importance of factors (c) and (d).

Fabric Filter Apparatus - The mechanical shake cleaning apparatus was the same equipment used in a previous fabric filter cleaning mechanisms

study.[5] The bag mounting and shaking assembly are shown schematically in Figure 29. A load cell installed in the shaker arm was used to measure bag tension while the shaking frequency was sensed through a microswitch adjacent to the motor shaft. A parallel clean air inlet containing a high efficiency filter (HEPA) was added to the system immediately before the fabric filter so that essentially particle-free inlet air could be supplied for certain tests. The system is portrayed schematically in Figure 30. The properties of the 10-foot long, 6-inch diameter, filter bag are given in Table 16.

Table 16. FABRIC PROPERTIES, LABORATORY MECHANICAL SHAKE CLEANING TESTS

Material	Cotton
Weave	Sateen
Weight, oz/yd^2	10
Yarn count	95 x 58
Permeability[a]	13
Manufacturer's no.	960
Manufacturer	Albany International Industrial Fabrics Division[b]

[a]Gas flow in ft^3/min per ft^2 of fabric at 1/2-inch water pressure drop.

[b]Now Globe Albany, Buffalo, New York.

Aerosol Properties - Coal fly ash, the primary test dust, was redispersed by a 90 psig compressed air ejector to produce a particle size distribution approximating the original material. A summary of the test dust size properties as measured in a previous study is presented in Table 17.

In addition, some tests were conducted using a low concentration fluorescein dye aerosol generated by an ERC Model 7330 Fluid Atomization Aerosol Generator. A charge neutralizer contained in the aerosol generator is claimed to assure an electrically neutral aerosol. The aerosol has been

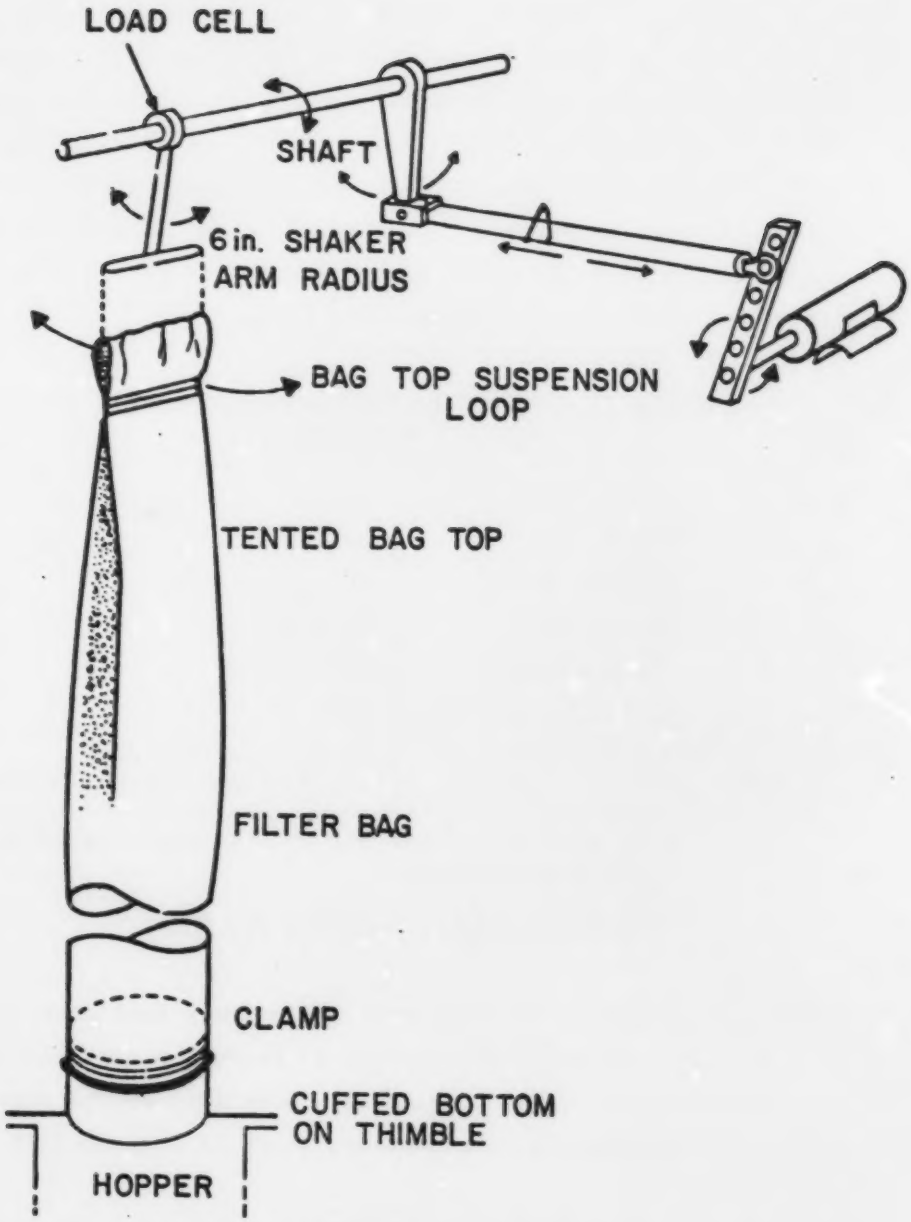

Figure 29. Schematic drawing, bag mounting and shaking assembly

1. Main Fan
2. Manual Valve
3. Automatic Valve
4. Fly Ash Hopper & Feeder
5. Feed Control
6. 10 ft. long x 6 in. dia. Bag
7. Partially Closed Filter House
8. Shaker Apparatus
9. HEPA Filter
10. Shaker Control
11. Dust Hopper
12. Hand Slide Valve
13. Sealed Drum
14. By-Pass Loop
15. Air Ejector
16. Dust Pickup

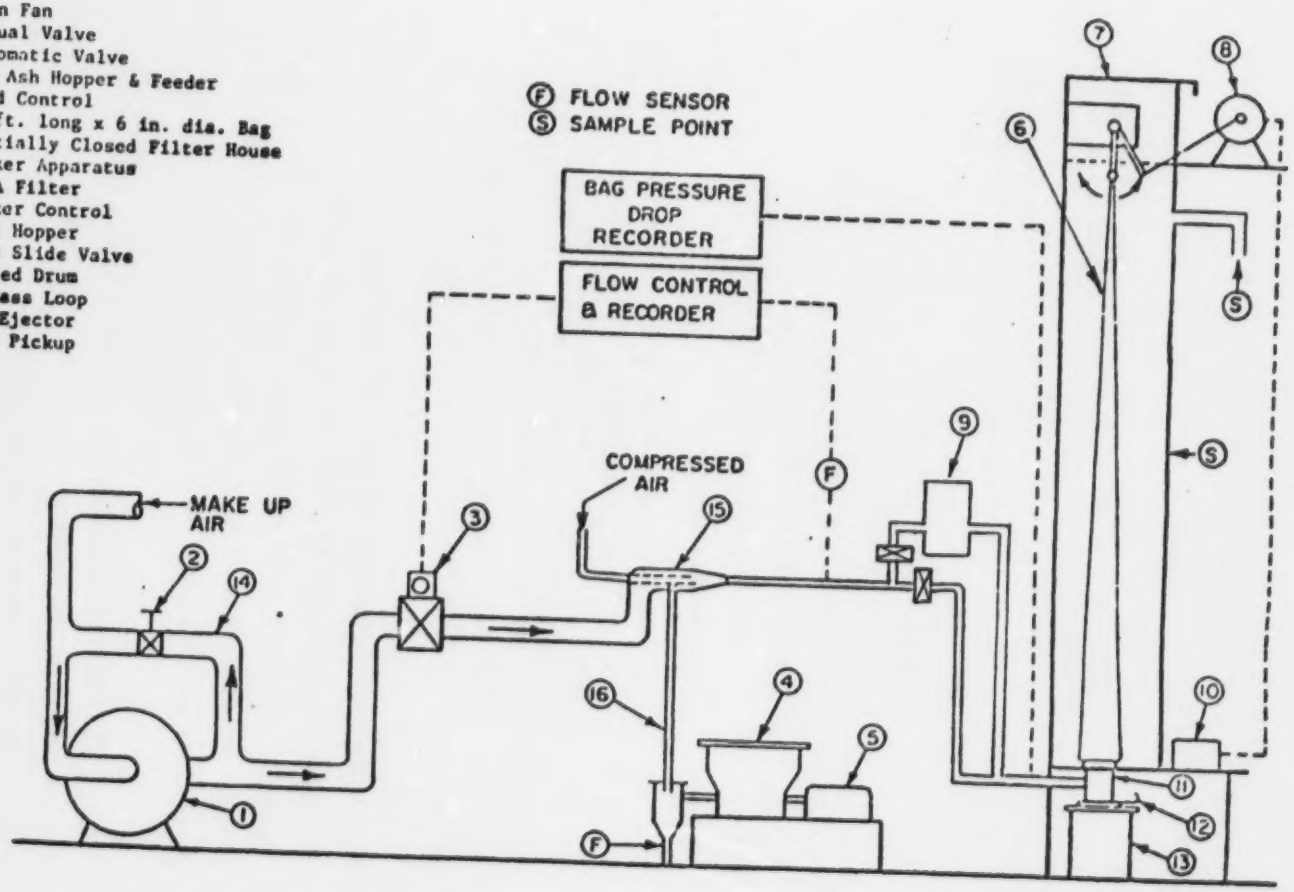

Figure 30. Schematic-experimental fabric filter system

reported[26] to have a mass median diameter of 0.2 microns and a standard deviation of 1.67.

TABLE 17. INLET TEST AEROSOL SIZE PROPERTIES[a]

	MMD microns	σ_g
Coal Fly Ash[b]		
Light field microscopy		
As received bulk dust	5.0	2.13
Dust shaken from bags	2.4	1.77
Andersen cascade impactor		
Aerosolized dust	8.0	2.0
Fluorescein dye	0.2	1.67

[a]Inlet size properties. Coal fly ash properties were measured in a previous study.[5] Fluorescein size properties were reported by the manufacturer of the aerosol generator.[26]

[b]Source: Hopper of electrostatic precipitator, cyclone boiler.

The supply air delivered by the main fan was drawn from the room in which the filter system was located, such that considerable recirculation was involved. Nominal room conditions of about 68° ± 3°F and 62 percent ± 4 percent relative humidity were maintained by the mechanical shaking tests. No effects attributable to variations in humidity were observed.

Aerosol Measurement Techniques - Inlet fly ash mass concentration was determined from the measured dust delivery rate of the Acrison dust feeder and the measured system gas flow rate. The dust delivery rate, averaged over a period of 1 minute or more, varied by only ± 1 percent. The actual dust concentration arriving at the fabric, as reported by Dennis and Wilder,[5] was 30 percent lower than the gross inlet concentration due to settling in the hopper.

Dye concentrations at the filter inlet and outlet were determined by the same technique; i.e., collection at 1 ft^3/min upon 0.8 micron (AA) millipore filters. The dye was then washed from the filter and the fluorescence of the filtrate was measured with a Turner Fluorometer. Comparison with standard dye solutions yielded the mass concentration.

A Bausch and Lomb Dust Counter 40-1(B&L) was used to determine effluent particle number concentration for particles greater than 0.3 microns. The B&L is a single particle light scattering counter with a dial display and digital counter. Particle number concentrations greater than the following diameters were obtained directly from the B&L data output: 0.3, 0.5, 1.0, 2.0, 3.0, 5.0, and 10.0 microns. Any of these ranges can usually be accurately monitored over intervals of 5 seconds. Two problem areas, however, must be considered carefully. Concentrations over 10^6 particles/ft^3 may not be accurately measured by the B&L, because the presence of two or more particles in the counting chamber at the same time may register as a single particle. In addition, as the concentrations decrease below about 2000 particles/ft^3, longer averaging intervals are needed to provide statistically valid measurements.

Each range was monitored for an entire filtration cycle. The particle number concentration in each interval (i.e., 0.3 to 0.5 microns) could then be easily calculated. Repeat measurements on a single range indicated that the number concentration was reasonably constant from cycle to cycle. The B&L provided important data in that the particle number concentration could be monitored over very short intervals during the filtration cycle.

Mass concentration and size properties were calculated from the number concentration data obtained with the B&L. It was recognized that light scattering equipment is very sensitive to particle shape, surface characteristics, and refractive index.[27] Therefore, it is advisable to consider the mass or number concentrations determined by light scattering

not as absolute values but rather as relative results to be compared to similar measurements on the same dust. However, the B&L device offers the unique advantage of allowing effluent number and mass concentration data to be obtained over very brief time intervals and at very low concentrations, 10^{-4} to 10^{-8} grains/ft^3.

An Environment One Condensation Nuclei Counter (CNC) was used to determine the effluent number concentration for particles in the size range (0.0025 to 0.01 microns) to (0.3 to 3 microns). The lower size limit depends on dust properties and concentration while the upper size limit is affected by sampling line loss. In almost all cases the number of particles above 0.3 microns will be insignificant compared to the number of smaller particles. Since the CNC is affected by particle properties at high concentrations, it should be used at concentrations below 50,000 muclei/cm^3. In addition, concentrations below about 300-500 nuclei/cm^3 (8.5 - 14 x 10^6 nuclei/ft^3) may not be detected. Therefore concentrations that appeared to be 0 nuclei/cm^3 are reported as less than 300 nuclei/cm^3. This lower limit of the CNC is eight times the upper limit of the B&L.

Test Conditions - The filtration cycle, mechanical shaking parameters and filtration conditions are presented in Table 18. Tests were conducted on an automatic 10 minute cycle. Typical mechanical shaking cleaning parameters needed for effective cleaning were selected and held constant through each test. Nominal inlet dust concentration was 6.6 grains/ft^3 with an estimated 4.6 grains/ft^3 actually reaching the filter. Special tests, however, were conducted with only prefiltered room air flowing through the filter. Figure 31 presents the normal filter pressure drop as a function of time. During clean air filtration testing, the filter pressure drop remained at 1.7 inches of water throughout the cycle.

Results

Test Series No. 1 - The purpose of the first test series was to compare the effluent mass concentration from a normal cycle to the effluent mass

Table 18. TEST CONDITIONS LABORATORY FILTRATION OF FLY ASH WITH A MECHANICAL SHAKE CLEANED FILTER

	Test series 1	Test series 2	Test series 3
Filtration cycle, time-minutes			
Fan start	0.0	a	0.0
Compressed air ejector start	0.2	a	0.0
Dust feed start	0.25	a	0.0
Dust feed stop	7.0	a	7.0
Compressed air ejector stop	7.4	a	7.4
Fan stop	7.8	a	7.8
Shake start	8.15	a	8.15
Shake stop	9.0	a	9.0
Cycle restart	10.0	a	10.0
Mechanical shaking parameters			
Shaker arm amplitude,[b] in	1.0	a	a
Shaker arm frequency, cps	7.0	a	a
Static tension, lb	1.2	a	a
Dynamic tension,[c] lb	4.0	a	a
Filtration conditions			
Air-to-cloth ratio,[d] ft/min	3	a	a
Gas flow, ft^3/min	44	a	a
Temperature, ^oF	75	a	a
Dust	Resuspended fly ash	a	a
Inlet concentration,[e] $grains/ft^3$	6.6	a	a
Inlet dust size,[f] microns	8	a	a

[a] Value same as Test 1.

[b] One-half of the shaker arm stroke.

[c] Average tension measured at the top of the bag.

[d] Fabric properties are presented in Table 16.

[e] Previous measurements[5] indicate that about 70 percent or 4.6 $grains/ft^3$ actually reach the fabric. For certain tests within each series the inlet aerosol was filtered room air.

[f] Mass median diameter by Andersen impactor for an assumed particle density of 2 gm/cm^3.

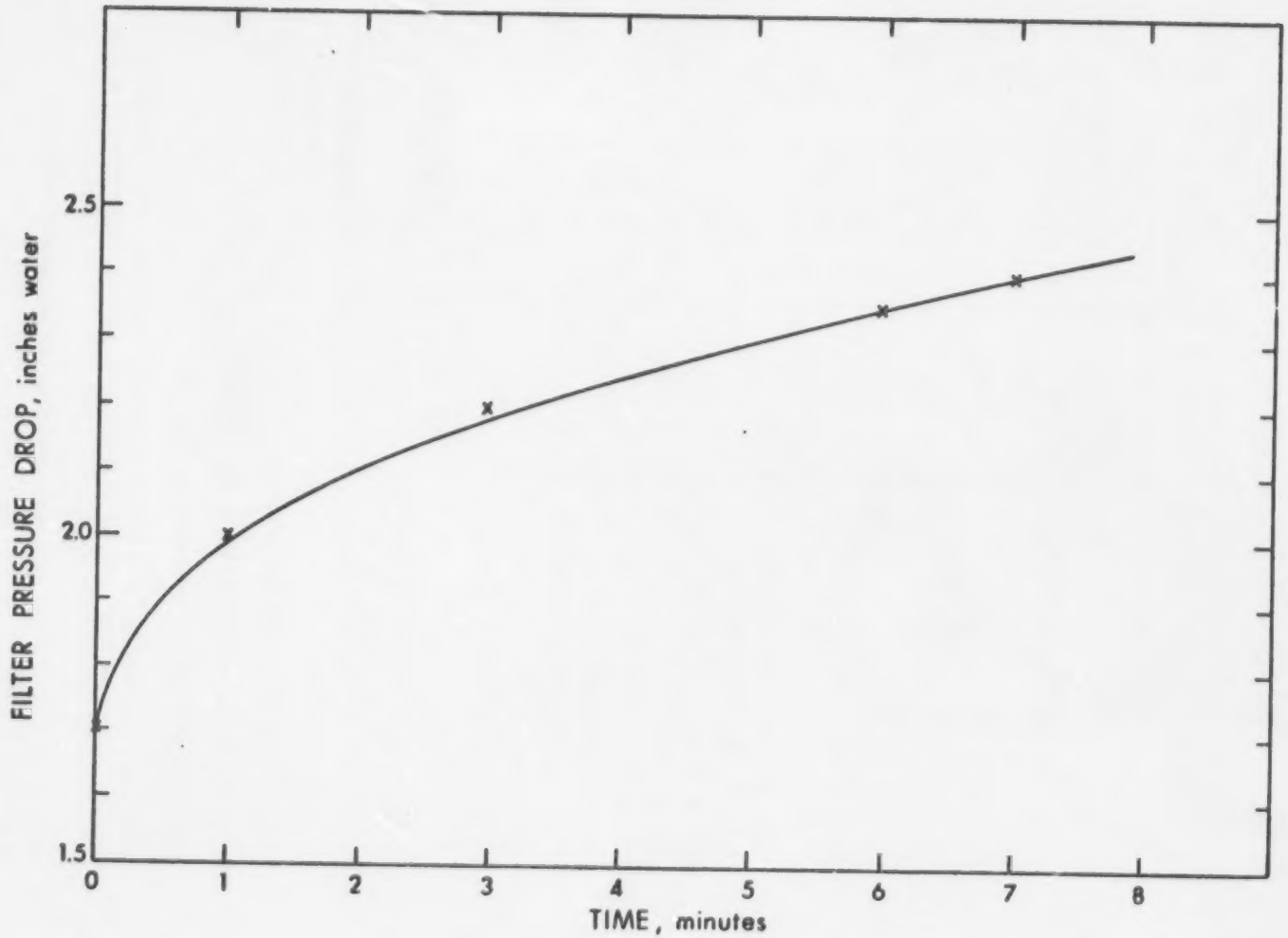

Figure 31. Filter pressure drop versus time for a normal cycle

concentration when the inlet aerosol was room air prefiltered by an absolute filter. Each clean air filtration cycle was preceded by a normal cycle. Two clean air filtration tests and one normal test were run. Outlet mass concentrations were calculated from B&L number distribution data and are presented in Figure 32. The two clean air tests show good agreement with each other. The effluent mass concentration during normal filtration was only slightly higher than that noted during clean air filtration, indicating that most of the effluent mass must have been some combination of particles that penetrated the filter during cleaning (source c, Table 15), and/or particles that were loosened during cleaning that were dislodged when air flow was resumed (source d, Table 15). During the first minute of filtration (the time frame of Figure 32), 96.5 percent of the effluent mass from a normal cycle and 98.8 percent of the effluent mass from a clean air cycle was emitted.

If the following assumptions are valid:

- The effluent particles resulted solely from dust that penetrated during cleaning (source c, Table 15).
- There was a continuous mixing process on the clean air side of the filter housing during flushing out when air flow was resumed.

Then the effluent concentration as a function of time might be predicted by the following equation:

$$C = C_o \exp(-Qt/V)$$

where C = Instantaneous outlet concentration, grains/ft^3

C_o = Initial outlet concentrations, grains/ft^3

Q = Gas flow rate, 44 ft^3/min

t = Time, minutes

V = Filter housing volume, clean air side only, 3.7 ft^3.

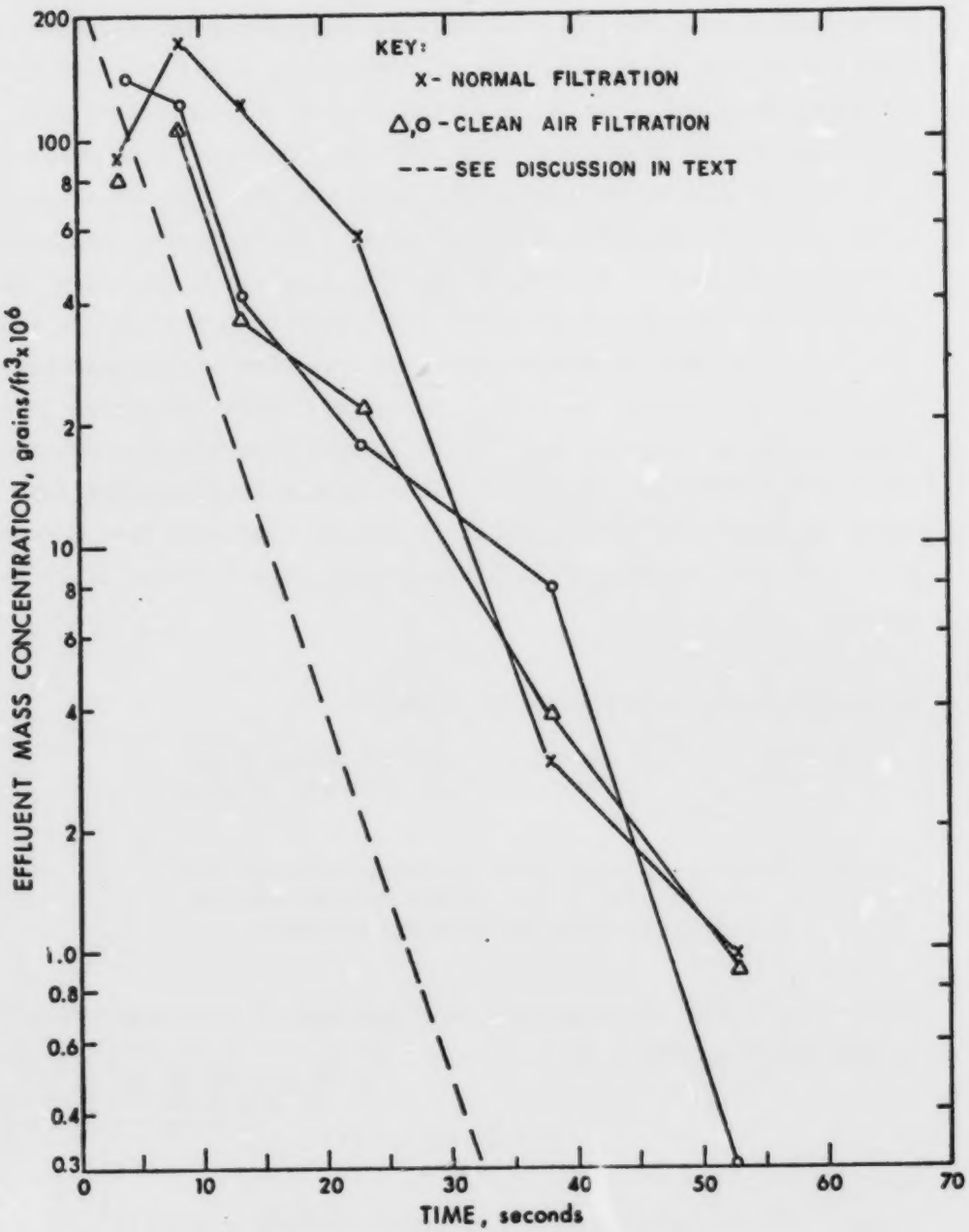

Figure 32. Test series 1, effluent mass concentration - normal filtration versus clean air filtration, B&L measurements converted to equivalent mass

The above equation is plotted as a dashed line in Figure 32 with an assumed initial concentration of 200 x 10^{-6} grains/ft^3. Although the predicted concentrations do not agree with the actual concentrations, particularly in later parts of the filtration cycles, the slopes of the curves show reasonable agreement. However, if the flushing out process was partly plug flow and the first assumption was still applied, then the decline in effluent should have been even steeper.

Figure 33 shows the same test results but plotted on a longer time scale. After the first minute of filtration, the effluent mass concentration was difficult to determine accurately because it was associated with a very small number of particles. Therefore, the data points in Figure 33 at 240 seconds represent the average effluent concentration for the period between 60 and 420 seconds. After 1 minute of filtration, the effluent concentration appears to result from factors (a) and (b); that is, dust that because of its size passes directly through the filter or dust that has been deposited on the filter and seeps through by successive deposition and reentrainment. Since essentially no dust is reaching the fabric filter during clean air filtration, the emissions are apparently caused by seepage, while the emissions during normal filtration are caused by both factors (a) and (b). This analysis would indicate that after 1 minute, 1/3 of the effluent mass is caused by seepage and 2/3 is a result of direct penetration. However, a firm conclusion might not be justified by the accuracy of the data in time frame after 1 minute. In addition, it is possible that during clean air filtration a very small amount of dust is reentrained from the hopper.

Test Series No. 2 - This test series was similar to the first test series except that a compromise was made between the time consuming determination of mass effluent concentrations and the easily determined total number concentration ($\geq$ 0.3 microns by B&L). In order to run a reasonable number of replicate tests in a short time, it was decided to monitor the $\geq$ 1 micron range on the B&L. This range included 99 percent of the effluent particles by mass and 20 to 30 percent of the effluent particles

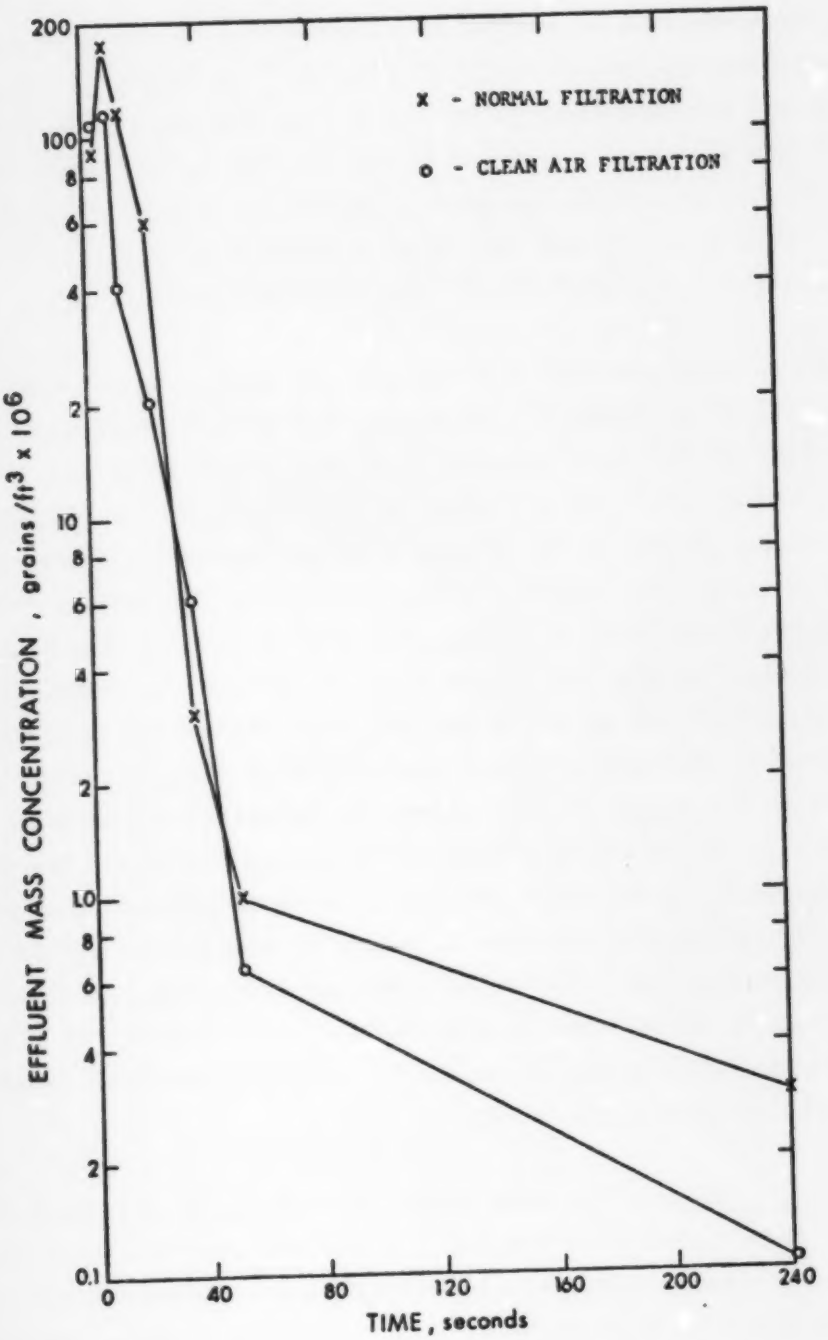

Figure 33. Test Series 1, effluent mass concentration - normal filtration versus clean air filtration, B&L measurements converted to equivalent mass.

by number. The concentration of particles greater than 1 micron should be an indication of the mass concentration. The results of the second test series are presented in Figure 34. Each curve is the average result of three tests. Individual data points for each test were all within 25 percent of the reported average value. The effluent concentrations from the clean air tests and the normal tests were very similar. In addition, both curves are very close to the exponential decay curve that would be expected if all the effluent particles greater than 1 micron were caused by penetration during shake cleaning (source c, Table 15), and if there was a continuous mixing process on the clean air side. The exponential decay curve and the effluent concentration curves have almost identical slopes. However, the absolute concentration values show some differences due to sudden changes in mass concentration, which may have been a result of flow disturbances and/or pinhole plugs breaking free.

Test Series No. 3 - These tests were similar to the second test series but the automatic operation of the filter system was modified so that the fan, compressed air ejector, and dust feeder started simultaneously. With this change, dust was deposited on the filter from the start of the cycle instead of starting at 15 seconds, and a sudden flow change that previously occurred at 12 seconds when the compressed air ejector started was eliminated. The results of this test series are shown in Figure 35. These curves show that the effluent number concentration ($\geq$ 1 micron only) for normal filtration and clean air filtration are almost identical. In addition, both curves closely follow the exponential decay curve that would occur when the emissions are caused by dust that penetrates the filter during shake cleaning. It is quite likely that the number concentration $\geq$ 1 micron is an indication of the effluent mass and thus one can infer that most of the effluent mass was a result of particle penetration during shaking. However, the mixing process on the clean side of the bag may not be as complete as assumed in this analysis. If the flow on the clean air side was incompletely mixed, then one would expect a more rapid decay in effluent concentration. In any case, the vast

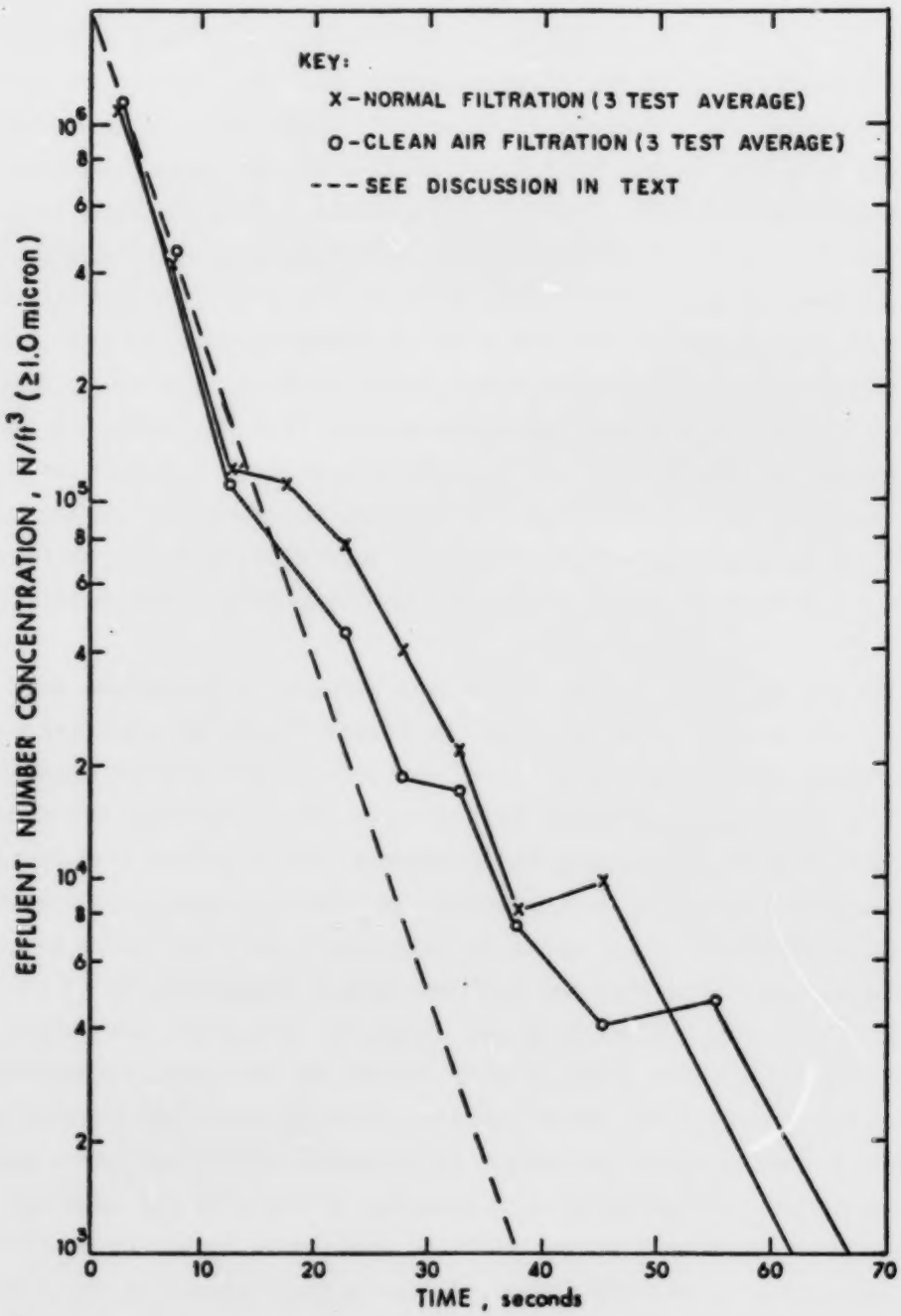

Figure 34. Test Series 2, effluent number concentration (≥ 1 micron) - normal filtration versus clean air filtration. B&L measurements

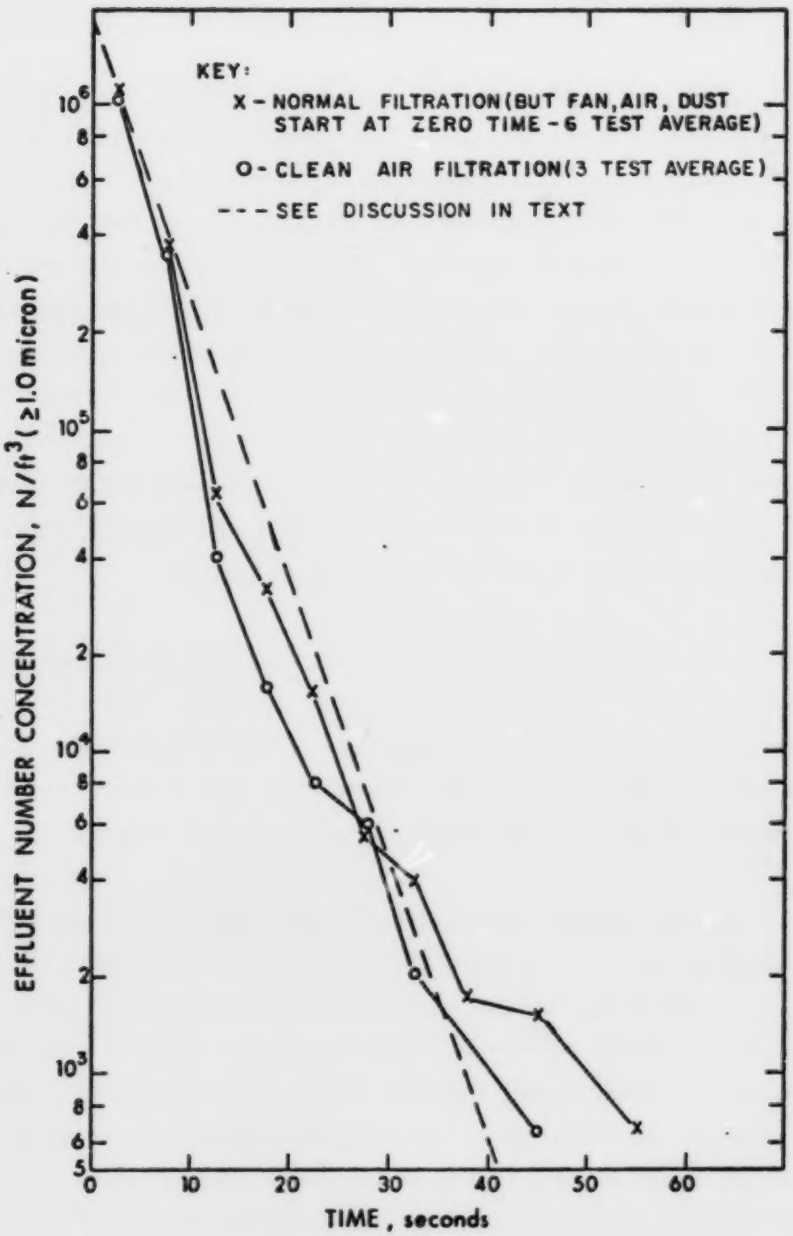

Figure 35. Test Series 3 effluent number concentration - normal filtration (fan, air, dust started at 0 time) versus clean air filtration, B&L measurements

majority of emissions are either dust that penetrated during shaking or dust that was dislodged from the filter when air flow was resumed.

Effluent Condensation Nuclei Test Results - A short test series was conducted using a condensation nuclei counter to monitor the effluent number concentration. The purpose of this test series was to obtain some insight to the effectiveness of fabric filters for the removal of particulates down to 0.01 microns. Theory for ideal filters has long predicted that a minimum (depending on particle and gas density and gas viscosity) collection efficiency should occur for 0.3-micron particles with higher efficiencies for smaller and larger particles. However, measurements below 0.2 microns are few. As part of this project, some preliminary measurements of the effluent nuclei concentration were made, but no measurements of the inlet concentration were attempted except when room air was being filtered.

During the initial test, room air with a measured nuclei concentration of 3.7×10^8 nuclei/ft^3 was used as the test aerosol. The effluent nuclei concentration was below the minimum detectable limit (8.5×10^6 nuclei/ft^3) for the entire filtration cycle. Therefore, the collection efficiency at all points in the filter cycle was at least 98 percent.

Next the effluent nuclei concentration was measured during a normal fly ash filtration cycle. The results are presented in Figure 36. There is about a 5-second delay in the response of the CNC which causes the low readings at the start of the filtration cycle. After 7 seconds, the effluent nuclei count rises sharply to 6×10^8 nuclei/ft^3. Within the next 40 seconds of filtration, the effluent nuclei count drops by a factor of at least 80 and is below the lower usable limit of the CNC. The inlet nuclei concentration was not measured but a very rough estimate can be made from the results of the first test. It is possible that the emission of very small particles such as condensation nuclei is a result of direct penetration and that collection efficiency is not affected by inlet concentration. If the above assumption was true then the greater

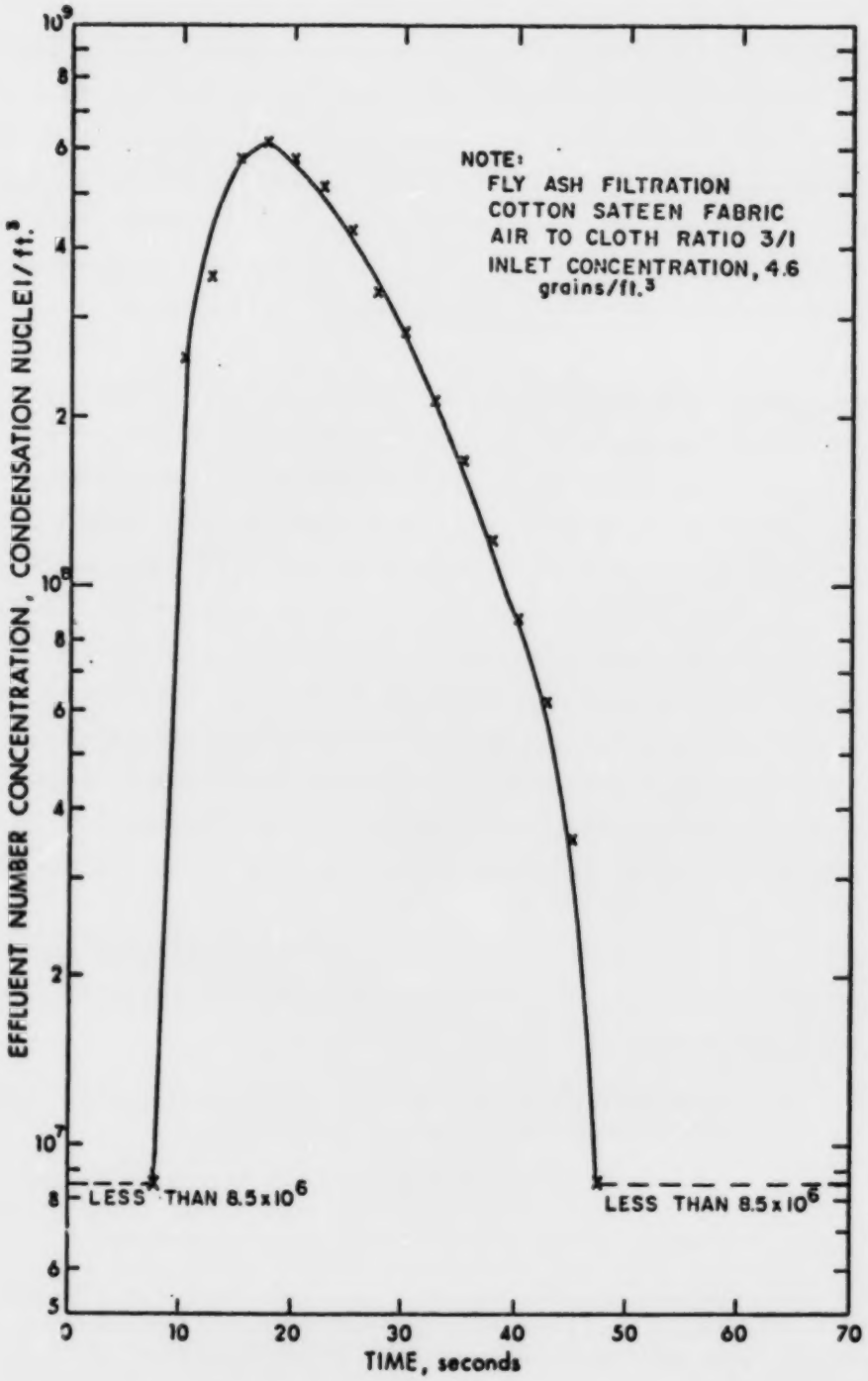

Figure 36. Effluent condensation nuclei concentration

than 98 percent efficiency measured in the first test could apply to the peak effluent concentration during the second test (6×10^8 nuclei/ft^3) indicating an inlet concentration during the second test of 300×10^8 nuclei/ft^3. Therefore the efficiency after the first minute of the second test may have been greater than 99.97 percent. With suitable dilution equipment the high inlet concentration can be measured directly thus providing more definitive results.

Fluorescein Dye Test Results - A series of tests using a fluorescein dye aerosol with a mass median diameter of 0.2 microns was conducted. A Turner Fluorometer was used to determine by fluorescence the inlet and outlet mass concentration. The tests are necessarily conducted at extremely low concentrations, about 5.6×10^{-5} grains/ft^3 compared to the normal fly ash concentration of 4.6 grains/ft^3. If the dye concentrations were 4.6 grains/ft^3, different efficiencies might be expected as the dust cake would be different. Furthermore, there are many differences between dye particles and fly ash particles, such as density, shape, surface characteristics, and electric charge properties, that may affect collection efficiency. The dye particles are, however, a useful tool for the investigation of fabric filtration principles.

The principle parameter investigated in this series of tests was the effect of the dust cake on efficiency. The following situations were investigated:

1. Efficiency of a bag that has just been cleaned. Only the residual dust remains on the bag.

2. Efficiency of a bag that has been filtering fly ash for 1 minute. The bag would have a dust loading consisting of the residual dust plus 13 grains/ft^2.

3. Efficiency of a bag that has been filtering fly ash for 15 minutes. The bag would have a dust loading of the residual dust plus 190 grains/ft^2.

The results* of the above tests are listed in Table 19. Percent penetration decreases from 0.87 to 0.18 to 0.01 for cases 1 - 3, respectively. The above results can be interpreted to indicate a large decrease in the percent penetration (79 percent/minute) at the start of filtration as the dust cake is restructured and then a more gradual decrease (19 percent/minute) as the dust builds up on the filter.

Two tests were run during which the filter was loaded with fly ash and dye simultaneously. The filter was then cleaned by mechanical shaking and filtration was resumed with prefiltered air. The effluent concentration during the first minute of clean air filtration (Table 19, Test No. 4) was approximately equal to the average effluent concentration for a cycle when the inlet aerosol contained dye. Test No. 4 demonstrated that during the first minute of filtration significant emissions occurred, consisting of particles that penetrated the filter during shaking (source c, Table 15) and/or particles loosened during shaking that penetrated when filtration was resumed (source d, Table 15). It seems likely that these effluent particles would be dye/fly ash agglomerates much larger than the original 0.2 micron particles. Comparing Tests No. 4 and 5 indicates that after 1 minute of clean air filtration, the effluent concentration was negligible.

Discussion and Conclusions

It has been suggested[23] that particulate emissions from a mechanical shake cleaned fabric filter can be attributed to some combination of the following sources:

a. Inlet dust that, because of its small size, passes directly through the filter, usually in progressively smaller amounts as the filter pore structure becomes plugged.

*The reported results for each test series are averages of three tests.

Table 19. RESULTS OF FLUORESCEIN DYE TESTS, MECHANICAL SHAKE CLEANED FABRIC FILTER

Test	Inlet concentration, grains/ft^3 x 10^5	Outlet concentration, grains/ft^3 x 10^5	Outlet concentration averaging period, minutes	Penetration, percent	Collection efficiency, percent
1. Just cleaned filter that had been loaded with fly ash.	5.6	0.049	7.8	0.87	99.13
2. After 1 minute of fly ash filtration.	5.6	0.0099	6.5	0.18	99.82
3. After 15 minutes of fly ash filtration.	5.6	0.00076	15	0.01	99.97
4. Just cleaned filter that had been loaded with dye and fly ash.	Negligible	0.056	1 (first minute)	-	-
5. Just cleaned filter that had been loaded with dust and fly ash.	Negligible	0.0033	7.8	-	-

b. Dust that migrates through the filter by successive deposition and reentrainment under the combined effects of aerodynamic and mechanical (vibration) forces. Such dust penetration is often referred to as "seepage" in commercial parlance.

c. Dust dislodged from the shaken fabric during cleaning that has penetrated to the clean air region. Resumption of air flow flushes out the clean air side of the system, often producing a visible puff of dust.

d. Dust loosened during the cleaning process whose bonding to the fibers or interstitial dust structure is not sufficiently strong to resist the combined dislodging forces (aerodynamic and mechanical flexure) when system air flow is resumed.

It was demonstrated that during fly ash tests with mechanically shaken cotton sateen filter that the effluent number concentration greater than 1 micron diameter, which account for most of the effluent mass, probably penetrated the filter during cleaning (source c). It should be realized that this result applies to the specific test conditions; i.e., dust, fabric, humidity, filtration velocity and cleaning parameters. However, it is not uncommon for the effluent concentration to decrease very sharply in the early stages of a filtration cycle.[1,2,29] Goldfield[29] has reported asbestos filtration measurements on an industrial cotton sateen fabric with an inlet concentration of 1 grain/ft^3 and an outlet concentration of about 0.00008 grain/ft^3. In this paper,[29] Goldfield reports that measurements with a Sinclair-Phoenix Photometer showed extremely low concentrations during normal filtration, a large increase in concentration during mechanical shake cleaning and a surge of dust that took 2 to 3 minutes to dissipate following resumption of air flow. It would appear that the asbestos emissions were primarily a result of sources (c) and (d) with some contribution from source (a).

The above discussion and the previously outlined fly ash results as determined with the B&L suggest the following conclusions:

- Effluent concentration from fabric filters cleaned by mechanical shaking, particularly those with efficiencies near 99.97 percent, may not bear any simple relationship to the inlet concentration as the emissions may be caused by movement of the dust cake, sources (c) and (d), and only partly by direct particle penetration.

- For the same reasons, outlet particle size (mass) may not be simply related to the inlet particle size. In fact, agglomeration of particles on the filter may lead to an outlet aerosol that is coarser than the inlet aerosol in the case of fume filtration.

- If extremely high efficiencies are required, for instance in collection of a hazardous material or possibly recycling air to a working area, recycling of the early effluent may be desirable.

Concentration measurements with a condensation nuclei counter showed that the tested fabric filter removed the smallest particles (0.01-0.2 microns) very effectively. More extensive testing should be performed to develop definitive experimental data on the capability of fabric filters to control particulates in the 0.01 to 0.2 micron range.

Tests with a fluorescein dye aerosol having a mass median diameter of 0.2 microns led to the following conclusions:

- Fly ash dust loading on the filter reduced dye penetration from 0.87 percent to 0.18 percent to 0.01 percent as the filter dust holding was increased from residual only to residual plus 13 grains/ft^2 to residual plus 190 grains/ft^2.

- Effluent dye concentrations during the first minute of filtration from a just cleaned filter with an inlet concentration of 5.7×10^{-5} grains/ft^3 and from a just cleaned filter that had been previously loaded with dye and fly ash but was filtering clean air were about 5×10^{-7} grains/ft^3. These tests again demonstrate that effluent concentration is not always directly related to inlet concentration and that sources (c) and (d) are significant sources of emissions.

PULSE JET CLEANING

Objectives and Approach

Parameters influencing the performance of pulse jet cleaned filter systems have been investigated by GCA in previous studies.[5] The emphasis of these past studies was to determine the effect of several parameters on filter resistance, effluent concentration, and effluent size properties. A key observation was that dust removal, as in the case of mechanical shake cleaned bags, was highly dependent on acceleration imparted to the fabric, in this case by the compressed air pulse. Although time did not permit quantitative measurements, it was suspected that the tightness or slackness of cloth tube fit would alter significantly the dust removal characteristics of a specific pulse jet system and that modification of the pressure/time characteristics of a compressed air pulse would produce improved filter performance.

The current test series was designed to further investigate the effects of bag fit, pulse type, and pulse supply pressure on effluent concentration and filter pressure drop. Bag fit was varied by using either a normal 4-1/2 inch diameter supporting cage for the normally taut bag tests or a 3-3/4-inch diameter supporting cage for the loose bag tests. Normal direct pulses and damped (indirect pulses) were generated by operating with the valve to the damping tank (Figure 37) closed or open. Pulse supply pressures of 60 psig and 100 psig were used.

Apparatus, Techniques and Materials

Fabric Filter Apparatus - The filter assembly used in this study is shown in Figure 38. Dusty air entered near the bottom of the housing with subsequent fallout due to inertial and gravitational effects. Filtration was on the outside of a 4 foot long, 4-1/2 inch diameter bag supported by a wire cage. The wire supporting cage consisted of 10, 1/8 inch steel rods spaced at equal intervals around the circumference of the bag and five

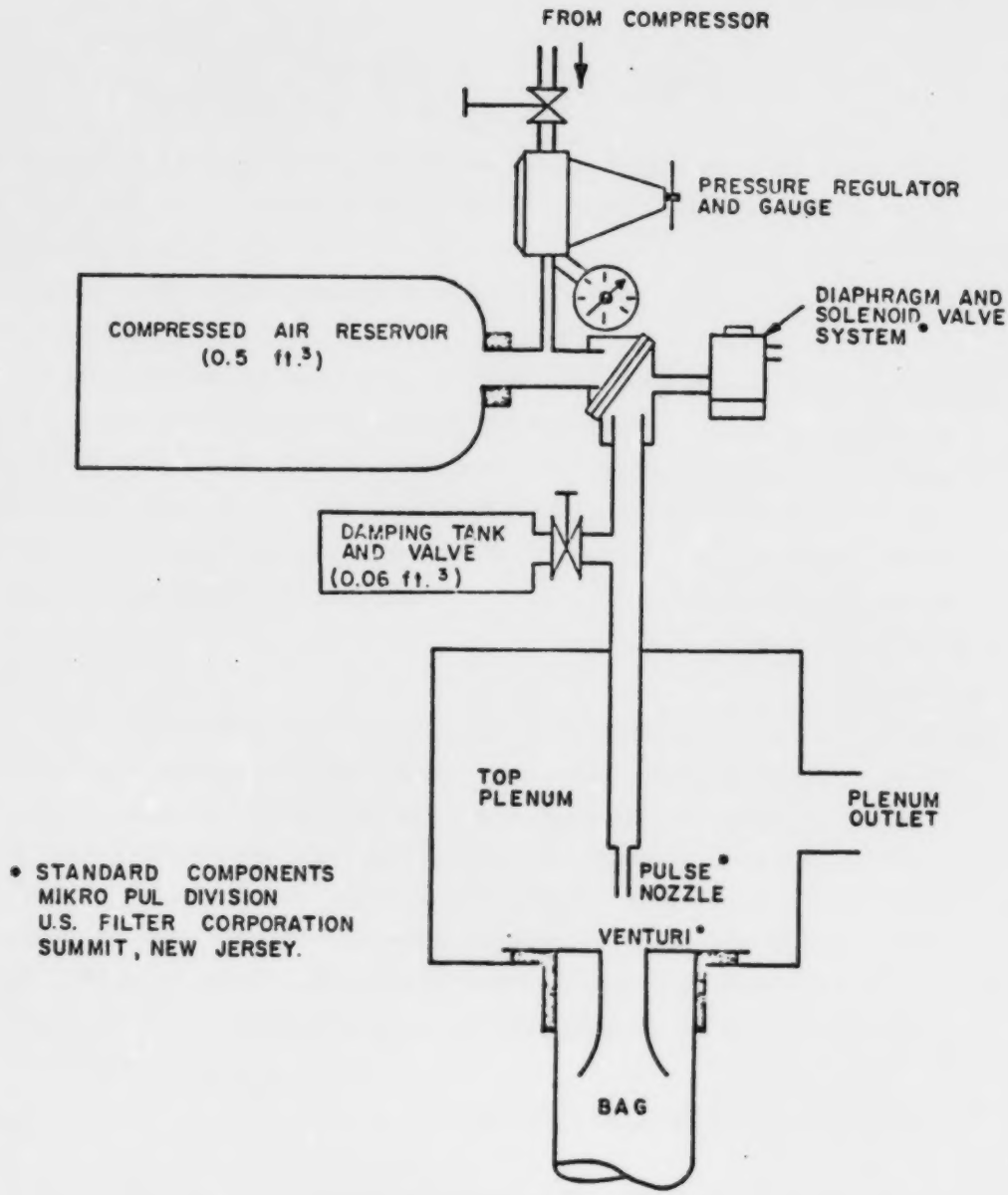
FROM COMPRESSOR
PRESSURE REGULATOR AND GAUGE
DIAPHRAGM AND SOLENOID VALVE SYSTEM •
COMPRESSED AIR RESERVOIR (0.5 ft.³)
DAMPING TANK AND VALVE (0.06 ft.³)
TOP PLENUM
PLENUM OUTLET
PULSE NOZZLE •
VENTURI •
BAG
• STANDARD COMPONENTS MIKRO PUL DIVISION U.S. FILTER CORPORATION SUMMIT, NEW JERSEY.

Figure 37. Standard pulse delivery system

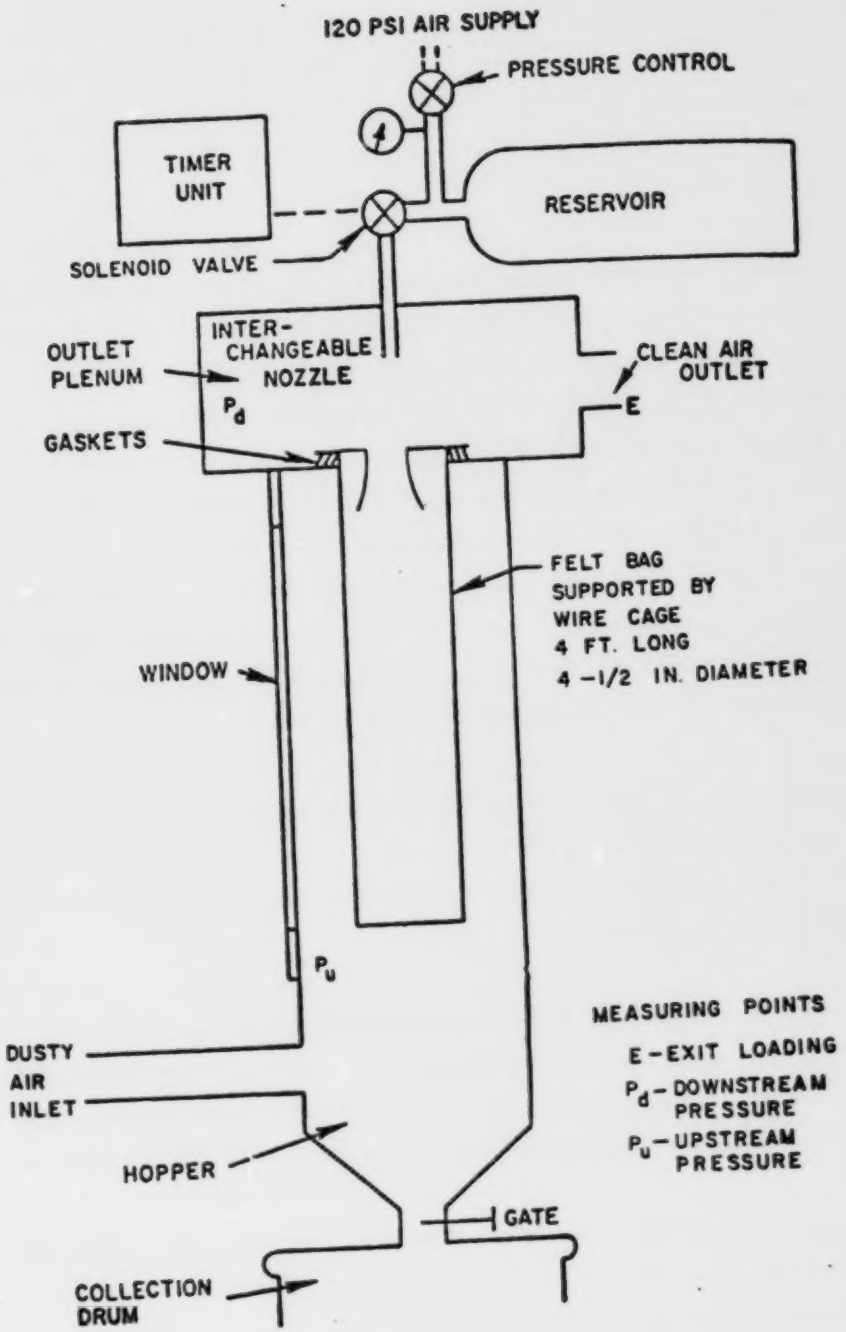

Figure 38. Schematic of pulse jet cleaning assembly

stiffening rings spaced at equal intervals along the length of the bag. Both bag and cage were fastened to a Venturi which was then mounted in the filter housing. The filter housing around the 4-1/2 inch diameter bag was 8 inches x 8 inches in order to maintain an upward dust transport velocity of about 100 fpm.

A schematic drawing of the pulse delivery system was presented in Figure 37. The compressor delivered air at 120 psig, at room temperature and free of water droplets. A pressure regulator was used to set the pulse supply pressure and the reservoir pressure. The solenoid valve system consisted of a 3/4-inch diaphragm valve operated by pilot valve. A 0.10 second electrical signal set by a digital electronic timer activated the solenoid valve. Previous measurements had shown the actual valve open time to be 0.15 seconds due to a mechanical delay within the valve. As previously mentioned the damping tank and valve were used to modify the pressure wave during cleaning. The pulse nozzle was a standard 1/4-inch pipe with an inside diameter of 0.35 inches.

The test fabric was an 18 oz/yd^2 Dacron felt. Fabric characteristics and bag dimensions are listed in Table 20. Beford performance data were collected, the fabric filter system was operated for 26 hours or over 1500 cleaning cycles.

Filtration conditions and cleaning parameters, except those deliberately varied for experimental purposes, were held constant during the test program. Air to cloth ratio was 8 ft/min during all tests. The bag was cleaned once each minute by a 0.15 second pulse of compressed air.

Aerosol Properties - The test dust was fly ash redispersed by 90 psig compressed air ejector as described in the mechanical shake cleaning section. The redispersed dust had a mass median diameter of 8 microns with a geometric standard deviation of 2. Inlet dust concentration was 20 $grains/ft^3$ as determined from the dust feed rate and gas flow rate and fallout in the hopper was estimated to be 50 percent. Effluent mass

concentration was determined by standard sampling methods using glass fiber filters. Two to four effluent samples were taken during each test. Sampling time for each sample varied between 15 and 60 minutes depending on the dust concentration, thus each sample covered 15 to 60 cleaning cycles. Gas temperatures was 70°F and the relative humidity was between 70 and 75 percent.

Table 20. BAG CHARACTERISTICS, PULSE JET CLEANING TESTS

Material	Dacron felt, needled
Style	A136B
Weight, oz/yd^2	18
Permeability[a]	35
Fiber diameter (D_f) microns	20
Felt thickness, cm	0.17
Fiber volume fraction (V)	0.26
Pore size (D_p),[b] microns	34
Bag diameter, in	4-1/2
Bag length, ft	4
Manufacturer	Albany International[c]

[a]Gas flow ft^3/min per ft^2 of cloth area at 1/2-inch water pressure drop.

[b]$D_p = D_f \left(\frac{I-V}{V}\right)^2$

[c]Now Globe Albany Inc, Buffalo, New York.

Results

A total of eight tests were run, each lasting about 7 hours. The tests were listed in Table 21 in the order that they were performed. Although effluent samples were taken throughout each test, those samples taken before 1 hour of equilibration were not included in the final determination of average effluent concentration.

Table 21. OPERATING PARAMETERS FOR PULSE JET CLEANING TESTS

Test no. 1	Pulse supply pressure psig	Bag fit	Pulse type
1	60	Taut	Indirect
2	100	Taut	Indirect
3	60	Taut	Direct
4	100	Taut	Direct
5	60	Loose	Indirect
6	60	Loose	Direct
7	100	Loose	Indirect
8	100	Loose	Direct

Figure 39 shows the effect of pulse supply pressure, pulse type and bag fit on effluent mass concentration. Samples taken during the taut bag tests show good agreement with each other while those taken during the loose bag tests show some variation.

Generally, during all tests, the effluent concentration declined and the filter pressure drop rose very gradually as the test continued. Although longer equilibration times would have been preferred, in most cases the data scatter is not serious and valid conclusions may be drawn.

Both pulse type and pulse supply pressure showed large effects on effluent concentration. The results show that a change in pulse supply pressure from 60 to 100 psig increased the effluent concentration 5 to 7 times for direct pulses and 13 to 24 times for indirect pulses. Effluent concentration from direct pulses was 15 to 23 times higher at 60 psig and 5 to 9 times higher at 100 psig than for indirect pulses.

Changing from a taut bag to a loose bag generally doubled the effluent concentration, but caused no change for 100 psig indirect pulses. A short test using a loose bag and an 80 psig indirect pulse was also conducted.

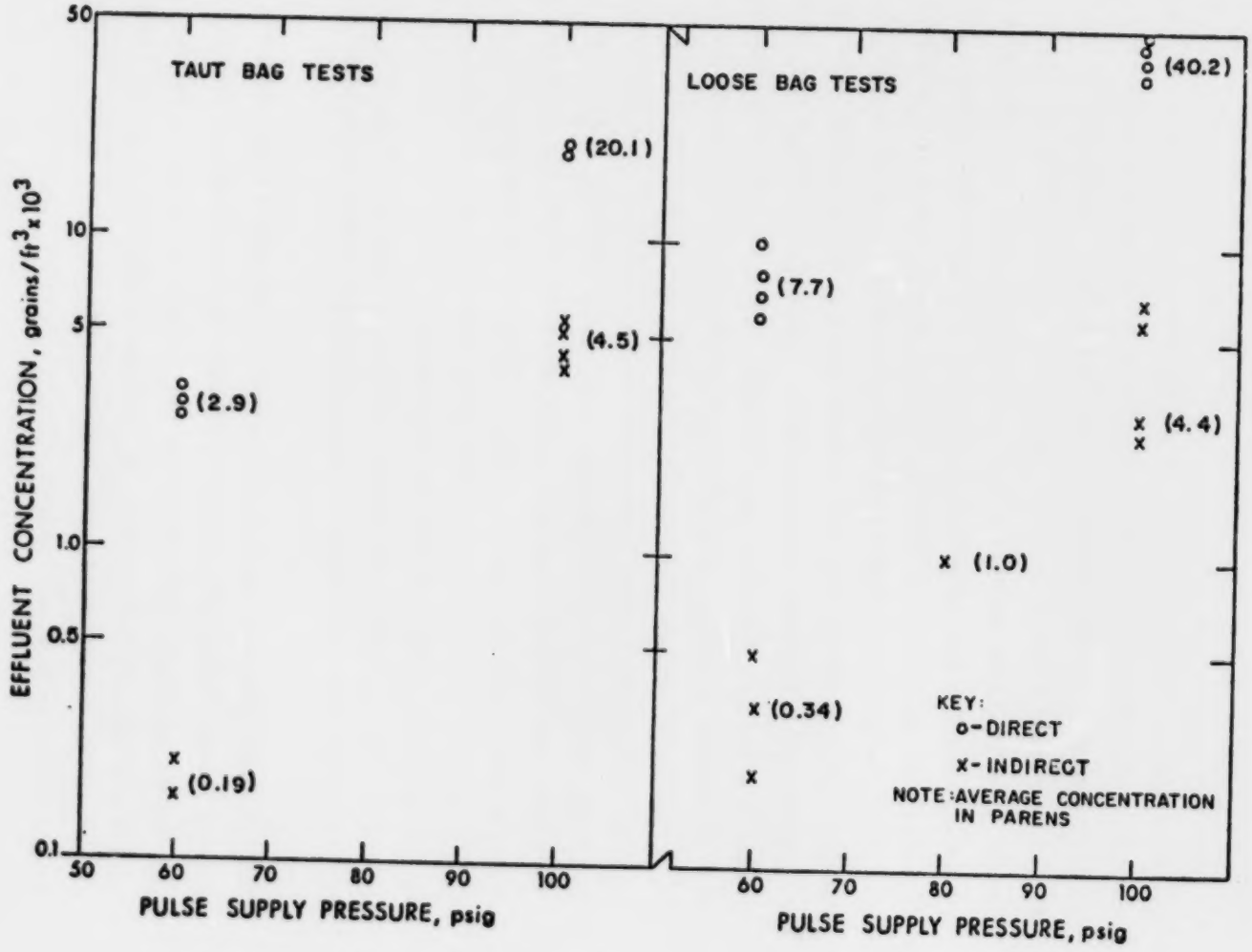

Figure 39. Effect of pulse supply pressure on effluent concentration

The result suggests a possible straight line relationship between the points in Figure 39.

Filter pressure drop was monitored during each test. A 24 hour chart recorder was used to determine pressure drop trends over periods of 1/2 hour or longer. Filt r pressure drop versus time for single filtration cycles was periodically recorded manually. A plot of filter pressure drop versus time would be expected to have the same slope for all tests in this study. Therefore the average and residual pressure drops would be proportional to the terminal filter pressure drop. Since the terminal pressure drop could be determined with greater accuracy than the residual or average pressure drop; bag fit, pulse type and pulse supply pressure were correlated with terminal pressure drop. Terminal, average and residual pressure drops for the taut bag, 60 psig, direct pulse test were 4.85, 4.2 and 2.1 inches of water respectively. Terminal filter pressure drop results for cleaning cycles at the end of each test are presented in Table 22. Bag fit had only a small effect on filter pressure drop. Pressure drop for loose bag tests was 2 to 7 percent lower than taut bag tests with the exception of the 60 psig indirect pulse tests in which the terminal pressure drop for the loose bag was 5 percent higher. Increasing the pulse supply pressure drop, from 60 psig to 100 psig, had a larger effect on terminal filter pressure drop, decreasing the pressure drop 13 to 16 percent. Pulse type also had a significant effect on filter pressure drop with direct pulses decreasing the terminal filter pressure drop by 12 to 19 percent.

The effluent concentration was found to be related to the terminal filter pressure drop within the confines of the test variables. That is when the change in filter pressure drop was caused by either a change in pulse supply pressure or pulse type, the effluent concentration was strongly correlated with the terminal filter pressure drop. A least squares fit of the equation $y = ae^{bx}$ where:

y = effluent concentration

a = computed constant

b = computed constant

x = terminal filter pressure drop

was computed. The results are presented in Figure 40. Both lines had a correlation coefficiency of 0.96 and there equations were:

Taut bag $y = 1.26 \times 10^7 e^{-3.2x}$

Loose bag $y = 1.09 \times 10^6 e^{-2.67x}$

Similarly when the data points for both tests were combined, there was still a good correlation between effluent concentration and terminal filter pressure drop. The computed equation was:

$$y = 1.65 \times 10^6 e^{-2.80x}$$

with a correlation coefficient of 0.93.

Table 22. TERMINAL FILTER PRESSURE DROP RESULTS

	Pulse supply pressure, psig	Terminal filter pressure bag, inches water	
		Direct	Indirect
Taut bag			
	60	4.85	5.50
	100	4.15	4.80
Loose bag			
	60	4.70	5.80
	100	3.85	4.70

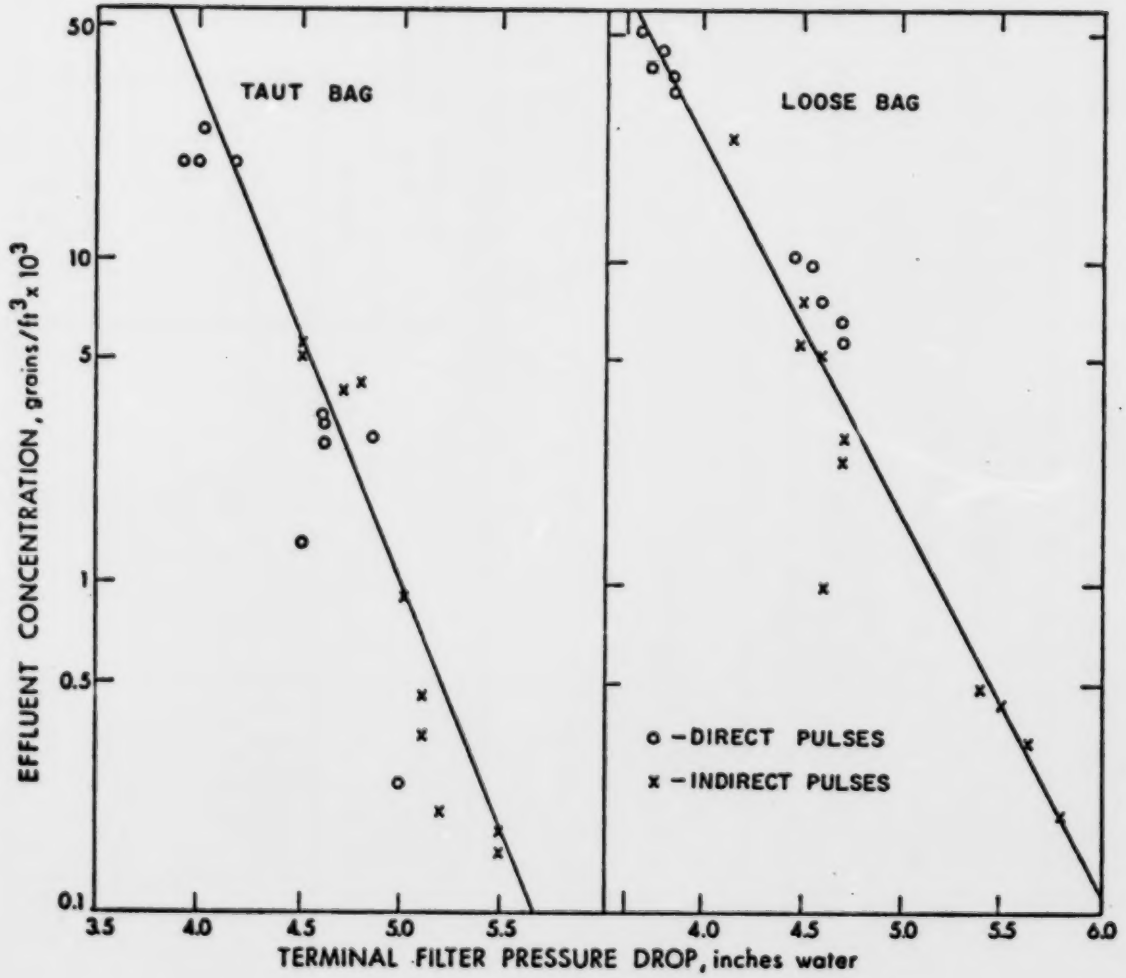

Figure 40. Relationship between filter pressure drop and effluent concentration

Discussion and Conclusions

The effect of pulse supply pressure, pulse type and bag fit on effluent concentration for a single bag fabric filter were investigated. Duplicate tests and sampling were utilized to determine accurately the magnitude of the above effects for the specific aerosol fabric system. Pulse supply pressure and pulse type exhibited larger effects on effluent concentration than previously reported by Dennis and Wilder.[5] However, these differences may have been caused by slightly different test conditions; i.e., inlet concentration and humidity. Effluent concentration ranged from 0.00019 grains/ft^3 for 60 psig indirect pulses to 0.0201 grains/ft^3 for 100 psig direct pulses when the bag was normally taut. When a loose bag was used the effluent concentration range was between 0.00034 and 0.0402 grains/ft^3. Bag fit had a minor effect on effluent concentration with the loose bag doubling the effluent concentration.

High pulse supply pressure, direct pulses and a loose bag all tended to cause lower filter pressure drop. Terminal filter pressure drop ranged from 3.85 to 5.80 inches of water. However, filter pressure drop increased slowly as each test progressed and longer equilibration times would have been desirable.

The results show that the efficiency of a pulse jet cleaned fabric filter can be sharply improved by decreasing the pulse supply pressure. Modification of the pulse characteristics can also cause a large improvement in efficiency. However, in both cases improvements are obtained at the expense of an increased filter pressure drop.

CHAPTER V

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APPENDIX

CONVERSION FACTORS FOR BRITISH AND METRIC UNITS

To convert from	To	Multiply by	To	Multiply by
^{o}F	^{o}C	$\frac{5}{9}$ (^{o}F-32)	-	-
ft	meters	0.305	centimeters	30.5
ft^2	$meters^2$	0.0929	$centimeters^2$	929.0
ft^3	$meters^3$	0.0283	$centimeters^3$	28,300.0
ft/min	centimeters/sec	0.508	meters/sec	5.08×10^{-3}
ft^3/min	$centimeters^3$/sec	471.9	$meters^3$/hr	1.70
in	centimeters	2.54	meters	2.54×10^{-2}
in^2	$centimeters^2$	6.45	$meters^2$	6.45×10^{-4}
oz	grams	28.34	grains	438.0
oz/yd^2	$grams/meter^2$	33.89	$grams/centimeter^2$	3.39×10^{-3}
grains	grams	0.0647	-	-
$grains/ft^2$	$grams/meter^2$	0.698	-	-
$grains/ft^3$	$grams/meter^3$	2.288	-	-
lb force	dynes	4.44×10^5	Newtons	0.44
lb mass	kilograms	0.454	grams	454.0
lb/ft^2	$grams/centimeter^2$	0.488	$grams/meter^2$	4880.0
in H_2O	cm H_2O	2.54	$Newtons/meter^2$	965
in H_2O/ft/min	cm H_2O/cm/sec	5.00	$Newtons/meter^2$/cm/sec	490.0